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PREFACE

WHEN invited to write the present work I felt that I had little information to impart that was not already contained in one or other of the numerous excellent works on automobilism already published. And now that it is written, I make no claim to teach the already technically instructed—still less the great army of "experts"—anything new, being still the merest student in the great school of automobilism. Indeed, the former have no need of, and the latter would probably resent, anything of the kind; so beyond making a few suggestions here and there, based on my observation of recent practice, I have made no incursion into the theory of the subject. Nevertheless, much as a second or third year's man may bequeath his lecture notes of the previous year to a junior student, and thus materially assist the latter, I felt that I might approach the apparently sacrosanct subject of automobilism from that standpoint, and so produce a work of possible use to the motor-purchasing public; the more so that it would be the result of personal experience and several years of careful observation. Furthermore, being acquainted with most of the existing works on the subject —English and French—it appeared to me, speaking from the student's standpoint, that while some were more historical than technical or representative of modern practice, others sketchy and circumambulatory, and still others technically far advanced and presumptive of much previous knowledge, there was perhaps an opportunity for a work which, while historically accurate so far as I could make it, should also describe *how* and *why motors of various kinds work and how they are typically constructed* as a *prelude* to the study of the numerous excellent works and newspaper articles on driving them, or better still, to actual driving practice. We are fortunate, of course, in having such inestimably valuable journals as *The Autocar*, *The Automotor Journal*, *La Vie Automobile*, and others to bring the latest information—theoretical and practical—to our grasp week by week; but in their quality as newspapers it would be too much to expect them to keep on repeating the groundwork to the exclusion of those valuable descriptions of current developments which are so eagerly awaited and studied by that great bulk of their readers who have long since passed their novitiate.

Such a work, then, as I contemplated—and, I trust, have written—would, I imagined, simplify the above studies for the beginner. And, since driving is by no means the whole art of the subject, it would also, I hoped, by presenting the groundwork knowledge in a reliable form and giving an intelligent idea of the constitution of various motors, serve as a guide to purchasing in the first place, to driving with good results in the second, and thirdly, to avoiding breakdowns or needing repairs. From these standpoints, therefore, the present work has been written. Types of motors have only been mentioned so far as, in my judgment, the type affects or varies *working principles;* for since makes of motors and cars vary almost monthly, separate descriptions of each would merely have wasted space. I believe also that this method of description has enabled me to bring the matter actually up-to-date—a well-nigh impossible task when every make of motor and automobile is described. Furthermore, the latter has already been, and is being, done as well as possible in the columns of the journals mentioned above. Theory also I have intruded upon merely so far as it affects design and consequent working. I quite recognise that there is much that I have left unsaid, which would doubtless render the present work more complete, especially in regard to car-construction. But here, again, these details—after all, very variable—are voluminously described elsewhere. Finally, I may say that, recognising the impossibility of pleasing everybody, I have not tried. If this work serves the purpose of the beginner and I mislead him on no point, I shall be satisfied. If, again, some of the ideas expressed appeal favourably to the *cognoscenti*, I shall be flattered. To others I would say, as did the great Artemus, that "they can pay without going in." In other words, they need not read the book if it does not agree with their own ideas. I must, however, acknowledge my great indebtedness to all whose kindness and patience have taught me the little I know; to the *Autocar* and *Automotor Journal*, for the verification in numerous details I have been enabled to obtain from their valued columns; and to Messrs. F. R. Simms, C. C. Maudslay, and others, for the loan of many of the illustrations.

G. DE H.-S.

GLOUCESTER ROAD, N.W.

CONTENTS

PART I

HISTORICAL

CHAPTER I

ANCIENT PERIOD

Date of conception of automobile idea unimportant—Early patents and devices—Cugnot the first inventor-constructor—Why he failed—Trevethick and Vivian's the first practicable automobile—Roads ready for the automobile—"Walking" devices—Gurney and Dance—Walter Hancock and others—Reasons for failure—Tyrannous railway legislation—The Turnpike Trust—Plateways originally intended—Continental neglect—The first differential gear—Alphonse Beau de Rochas, the inventor of the four-stroke motor—Lenoir—Automobile idea always maintained in England though neglected abroad—Ravel—Rubber tyres—James Robson the inventor of the two-stroke motor—Others—Delamare-Deboutteville and Malindin invented first carburettor—Gottlieb Daimler—His career and work—Raffard—Carl Benz—Daimler's first motor—Panhard and Levassor—Other makers—Improvement—Influence of Leon Lefebvre's design—Bollée and Henriod—Difficulty of identification of type through alteration and blending—Why these favour production—Close of ancient, type-invention and application period . . . . *page* 1

CHAPTER II

MODERN OR DEVELOPMENT PERIOD

1890 the dividing era—Only two applications since—Modern or development period—Why previous mention of type is appropriate and necessary—Importance of the early nineties—British market assured, yet British engineers forestalled—Why—Continental revival—Confidence of the *cognoscenti*—Newspaper enterprise inaugurated first automobile race—Its immediate effect—Second race, and its effect on Continental capitalists—Cautious financing—Details of Paris-Bordeaux event—First American endurance trial—And the latest one—Mr. Henry Hewetson the first importer of an automobile—The Honourable Evelyn Ellis and Mr. F. R. Simms—No police traps—Sir David Salomon's exhibit—First British automobile journal—Mr. F. R. Simms founds the British motor industry—Third Continental race — Higher speed and power — Mr. F. R. Simms founds the Club — And with others secures the passing of Light Locomotives Act—First British motor-car run—Mr. H. J. Lawson—Eppstein invents compound motor—Pretôt the fore-carriage—Others—Neglect of the fore-carriage—Why singular—British industrial struggles—Why caused—British patent laws—Continental success—Paris-Dieppe—Still greater improvement—Commercial vehicle trials—British success—Second Paris-Bordeaux and Tour de France—Their effect on construction—British industry still struggling — Club trials — Their usefulness — Enormous advance shown by Paris-Berlin race—Continental construction still at fault—British cars beat all others in Glasgow run—Speed-trials at Cromer—British car scores again—An efficient voiturette—Paris-Vienna *cum* Gordon-Bennett race—British car wins Gordon-Bennett cup—Two British cars beat sixty-two Continental cars in A.C.G.B.I. hill-climbing and reliability trials—Continental racing fatalities—Paris-Madrid—Circuit du Nord shows safety of circuitous courses—This finally proved by the Gordon-Bennett race in Ireland—The Cup lost—Automobile controllability proved publicly by Irish fortnight—British cars shown equal to Continental—Especially at recent exhibitions—Great Britain leads in light-car construction—And in heavy commercial vehicles—Also the pioneer of the agricultural motor—Two motor-tractor cultivators—Their economic results—And future . . . . . *page* 17

PART II

DESCRIPTIVE

CHAPTER III

INTERNAL-COMBUSTION MOTORS

Theoretical definition—And for automobile purposes—The internal-combustion motor—Physical description—Actual nature—Described first by Beau de Rochas—His four-stroke cycle—Essentials of a four-stroke motor—Description, function, and mutual relation of essential parts—Variations of type functionally considered—Greater efficiency of few-part design—The Beau de Rochas cycle—How it acts—Loss of energy—Single-valve four-stroke examples—Physical advantages claimed—Why automatic (atmospheric) inlet valves are less efficient—Structural description and working of single-valve motors—The D'Ecquivilly valve—Duplex and triplex a.o. inlet valves—Water and air-cooling systems—Water jackets and radiators—How water circulation is effected—Thermal or natural circulation—Lubrication—Typical examples of methods employed—Gravity fed—Splash or oil-bath—Forced-feed—Mechanical—Physical—Centrifugal—Ignition systems—Age of electric ignition—Daimler's tube-ignition system—Its disadvantages—Hot-chamber ignition—Its merits—Adiabatic ignition—Catalytic ignition—Theoretically ideal—Practical difficulties—Electric ignition—High and low tension—Jump or rupture-spark—Essential parts functionally described—In high tension—Essentials for its efficiency . *page* 35

CHAPTER IV

INTERNAL-COMBUSTION MOTORS

(Continued)

High tension-electric ignition functionally described—The phenomena—The circuits—The distributing commutator—Methods of wiring—The dynamo and magneto—Their merits—Automatic sparkers—The rupture-spark—Essential parts described—Seldom used with high tension—Advantages of the rupture-spark—The low-tension system—Its merits—Reasons why it is superseding high-tension—The secondary spark-gap—How discovered—How it acts—Its demerits—A physiological comparison—The carburettor—Proportions of the inflammable charge by volume—Function of carburettor—Types: bubbling, surface, wick, and spray—Atomisers—Structure and merits of the last named—How they act—Sub-types—The defect—How corrected—Lunkenheimer type carburettors—Their merits—Mechanical distributors—An anatomical circumstance—And its motor parallel—The action of the pneumo-gastric nerve and the governor—Usual structure of the latter—Methods of governing—Their results compared physiologically—Why some are wrong—Present practice—The natural method . . . . . *page* 60

CHAPTER V

TWO-STROKE INTERNAL-COMBUSTION MOTORS: SILENCERS

Reasons for previous structural consideration—Two-stroke motor invented by James Robson—The cycle—The structural differences from four-stroke—The Robson cycle described—How two-stroke motors work—The Clerk two-stroke motor—Joseph Day's—Its structure and working—Physical defects—The Smalley two-stroke motor—Why some of these are defective—Compounded motors—The Bichrone—The Evans and other motors—The Heasman two-stroke motor—Its novel design and working—Advantages claimed compared with others on working results—Silencers—Their general structure and function—Back-pressure—How silencing is effected—The two methods described—Essentials for efficient silencing—The combination—Water-jacketed condensers—Inefficient devices—The rotary silencer—The Dunlop—Its structure and principle—The "Scottish-boiler" condensing silencer 83

CHAPTER VI

STEAM MOTORS

Types of steam motors—Similar in frame and certain parts to foregoing—Physical differences functionally considered—Also structural and mechanical differences—As affecting choice of type for automobile purposes—Advantages of compounding—Valves: their type and function—Differences in their action from those already described—Their actuating and controlling mechanism—Its structure and function different—The reasons why—Essential parts of mechanism—Why different—Why an eccentric is used instead of an intermittent cam—The Stephenson link-motion—How and why it acts—To vary speed or reverse engine—Non-intermittent cams—In Gardner-Serpollet steam motor—Other steam motors—Rotary motors—The Nègre semi-rotary—Its structure—Structure and action of its valves and controlling mechanism—Why semi-rotary in piston-effort on shaft, though actually reciprocating—Turbine motors—Why unsuited to auto-propulsion of vehicles . . . . . *page* 96

CHAPTER VII

BOILERS AND BURNERS

Condition of vehicular propulsion by steam—Governing type—The essentials—No steam-generator "fool-proof"—Types of boilers—Fire-tube boilers—Physical peculiarities and structure—Variations—Water-tube boilers—Difference in structure of various examples—Why tubes are curved in some of these—Rapid circulation, the object of water-tube-boiler design—Scotte, De Dion-Bouton, Wiedknecht, Savage, Thornycroft and Yarrow boilers—The Sergeant boiler—Its qualities—Structural departure from type—The physical result—"Flash" boilers—The type-link—Its structure and working—Conditions governing working of "flash" boilers—Which govern design—Reasons for automatic balance of ratios of water- and fuel-supply—Why a certain complexity is unavoidable—Balance interdependent or independent—Methods of balance—Mechanical linking of supply—Thermostats—Physically controlled valves—The Gardner-Serpollet generator—Its construction—How it works, and how its ratios are balanced—The Chaboche generator—Construction, working, and ratio-balance—The weak points—The White generator—Its unique structure—The physical result in its working—Its simple independent ratio control—Why water reserve always maintained—Its results—Liquid-fuel burners—How and why they work—How regulated—The various types—Multiple-jet pan-burners—Structure and working—Single-coil multiple jet burners—Structure and working—Single-jet burners—Structure and working—Variations—Single jets in multiple—Steam-induced burners—How they work—Steam driving fuel—Disadvantages mechanical and physical—Steam drawing fuel—The difference in results—The Hydroleum burner—The condenser—Various types . . 110

CHAPTER VIII

ELECTRIC MOTORS AND DYNAMOS

Ivan Jacobi, first constructor—Essential parts of an electric motor—Why their construction must be first considered—Construction of a field-magnet mass—Condition essential to its existence as a magnet—Construction of an armature core—Essential conditions—How it is wound and why—The construction of the commutator—Its function and relation—The result of conducting the electric current into the motor-mass—How the commutator works—The result—Torque—What accumulator cells are—How modified—Why grouped in a given number—Cell-elements—How composed—Why odd-numbered—Construction—Why made of lead—How improved—How connected and why—Action of the electrolyte—The Edison accumulator—Different types of electric motor—Series-wound—Shunt-wound—Typical effect of different winding on working of motor—Relative advantages and disadvantages—Compound-wound motors—Construction—How coupled and why—Types of compound-wound motors—The "Sine" motor—Why electric motors are heavy for their designed power—The controller—Its analogies—Its construction and working—How speed-changes are effected—C.E.M.F.—How varied—The effect on motor speed—Further reasons why electric motors must be heavy—Their high efficiency notwithstanding weight—Essential conditions restricting travel—The compound motor—How it removes these—W. H. Patton—Dowsing and Eppstein's improved compounding systems—Working and qualities — Lohner-Porsche system—Its working—The Germain system—Its structure—How and why it works—The results—Actually a variable change-speed gear—Compound motor heavier than internal-combustion motor of same power . . . . . . *page* 128

PART III

CONSTRUCTIONAL

CHAPTER IX

DESIGN AND CONSTRUCTION OF MOTOR-BODIES

Why types only discussed functionally hitherto—Why design and construction require closer detail description—Certain misconceptions—Public safe with the trade—No room for dogma—Beau de Rochas' four essential conditions and their object—Either type may conform—Modern compromise, and results claimed—Results claimed for short-stroke design—Continental practice—Nothing settled definitely—Present tendencies in other directions—The question of complication—Easy replacement—Standardisation—Carburation—How being improved—Why mixture unduly enriches at high speeds—How this tendency is corrected by—Krebs, Dunlop, Chenard-Walcker, Prunel, and others—Various methods—Power-wasting speed gears—The direct drive and motor control—The Chenard-Walcker system—How it differs—Why efficient—Variable-feed speed gears—Latest practice—Efforts to lighten and strengthen construction—Castings—Moulds—Some conditions ruling—How moulds are made—Reasons for special construction—Casting—Its difficulty—Disadvantages of "headless" cylinder castings—Water-jacketing considered—Variations of practice and design—Open-topped, separate—Open-faced, separate—The same with separate jackets—Objections urged—A suggestion—Its probable advantage—Napier practice—Inlet openings—Crank-case castings—How made—Accessibility—Why essential—Lower casting—Internal webs for intermediate bearings—The oil-bath . . . *page* 152

CHAPTER X

DESIGN AND CONSTRUCTION OF MOTOR PARTS

The machining of crank-case castings—Essentials of working—Cylinder castings—How machined—Limit of boring error—Finishing—Varying practice—Testing—Fitting—Conditions, and why essential—Parts described—Valve-boxes—A.O. and m.o.

inlet-valve boxes—Central downward-opening-valve boxes—How machined and fitted—How secured—How type varies manufacture—Valves—Why valve-seatings should be sunk—Advantages of central downward-opening-valves—Size of valve openings—Ignition plug castings—How machined—No compression lost if properly made—Pistons—Material—Construction—Position of pin—How pistons are machined—Piston-rings—How machined and fitted—Types of piston construction—The Hautier and Wolverine methods—The crank-shaft—How cranks are paired—Varying methods—An idea and a suggestion—De-Dion-type crank-shafts—Machining the shaft—Essential objects of working—Connecting-rods—How machined—The "big-end"—Varied construction—Advantages and otherwise—The "Weller" connecting-rod—Accessibility emphasised—Cam-shafts—How made and fitted—Cams—Gears—Material—Involute and epicycloidal teeth—Difference in working—Valve lifting spindles—Cam-shaft casings—Springs—The induction pipe—Essentials of design and reasons therefore—Machining—Exhaust pipes—Water-circulation pipes—Carburettors: how made and machined—How coils are wound—Testing the motor—The flywheel: how made and machined—Its relation (typical) to the clutch—Steam motor cylinders and crank-cases—Power-transmission and change-speed mechanisms—When a 20 h.p. motor is not a 20 h.p. motor—Why a steam motor needs no change-speed gearing—Why this device is essential—Why a clutch is essential; failing a zero-gearing device—Why speed gears and a clutch are needed on hills—And a reversing gear—Essential parts of a clutch—Types of clutches—Friction clutches: how they act—Jaw clutches—Why objectionable—The Martini magnetic clutch . . . *page* 175

CHAPTER XI

DESIGN AND CONSTRUCTION OF GEARS, CAR FRAMES, AND STEERING DEVICES, ETC.

The principle of spur-gear change-speeds—How they work—Construction of change-speed mechanism—Essential parts—The shafts, their function, mountings, and employment—The direct drive: how obtained—How the shafts work—How the gear-sizes are regulated—How paired and arranged—How shifted—Panhard system: how constructed—Disadvantages—Renault system—De Dion—Iden (M.M.C.)—Montauban-Marchandier—

How all work—The epicyclic train—Variable-feed change-speeds—The Barber gear: its structure and working—The Ricci gear: its unique construction and working—Two-speed gear—Why the differential is necessary—Its principles, structure, and working—The counter-shaft: its structure and working—Chain-drive—Tail-shaft and live-axle—How constructed—Why adopted—Thrusts: how they govern design in automobiles—And motor position—Position of brakes—The chassis or frame—The value of racing as a test of construction—Its effect in ten years—Structure of the chassis—The under frame—Frame connection with the car-body—Various constructions of frames—How made—Arbel frames—Variations of design—The Decauville design—Jointless one-piece pressed frames—Steering-axles—Types of construction—Why some are weaker—Effect of thrust material—Roller bearings—Why ball-bearings are dangerous in axle construction—Steering mechanism—Steering-arms essential for their interconnection—Typical construction—Essentials of steering mechanism—Why non-reversibility must be combined with elasticity in the device—Toothed gearing near the steering-axle—Some opinions on tyres—Misleading statistics—The element of such—Average failure percentages—Leather outer covers—Non-collapsible tyres—Leather cover deduces cost of maintenance—Reliability of pneumatics—Choosing pneumatic tyres . *page* 198

LIST OF ILLUSTRATIONS

FIG. PAGE
1. A TYPICAL FOUR-STROKE MOTOR 35
2. DIAGRAMMATIC SECTION OF TYPICAL FOUR-STROKE MOTOR 37
3. THE SIMMS-BOSCH MAGNETO (THE MAKE) . . . 38
4. ,, ,, ,, (THE BREAK) . . . 39
5. CAM-SHAFT AND MOUNTINGS 41
6, 7. SECTION OF SELBACH SINGLE-VALVE ENGINE . . . 46
8. THE CIRCUIT IN HIGH-TENSION IGNITION . . . 62
9–12. THE CYCLE OF A TWO-STROKE MOTOR . . 86, 87
THE HEASMAN MOTOR 89
13. AN ELECTRIC MOTOR DISMOUNTED 129
14. ,, ,, ,, ASSEMBLED 130
15. THE FIELD-COIL 130
16. THE MAUDSLAY MOTOR (SHOWING CRANK-CASE CONSTRUCTION) 172
17. A TYPICAL FOUR-CYLINDER MOTOR 175
18. THE MAUDSLAY MOTOR (SHOWING VALVE SITUATION) . 179
19. WOLVERINE CONNECTING-ROD CONSTRUCTION . . . 187
20. WELLER CONNECTING-ROD DETAILS 188
21. DIAGRAM OF CHANGE-SPEED 200
22. STEERING-WHEEL AXLE (TYPICAL) 213

THE AUTOMOBILE INDUSTRY

PART I

HISTORICAL

CHAPTER I

ANCIENT PERIOD

THE actual age of the idea of the mechanically propelled road-vehicle is a purely speculative matter, and likely to remain so. Tradition may or may not be correct in assigning it a date many centuries prior to the Christian era; but it is none the less certain that, were the matter to be verified to-morrow morning, the knowledge would be valueless from a practical standpoint. Thus it is of no earthly interest nor cogency in a work of the present kind. On the other hand, the date of the concrete expression of that idea is by no means uninteresting, however primitive that expression may seem in the light of modern engineering science. This, then, appears to be early in the seventeenth century; since a patent for "drawing carts without horses" was granted in 1619 to Ramsay and Wildgoose. It is only too probable, by the way, having regard to the latter name, and the nature of the invention, that this was the origin of the phrase, "a wild-goose chase," as a synonym for something utterly chimerical. Surely the belief is warranted, that the original phrase was "a wild-goose *chaise*"? Certain it is, however, that this device, as well as those of Jean Theson, Father Verbiest, Giovanni Banca, Sir Isaac Newton, Papin, Savery, and Vaucanson—all of which belonged to the same century—were of little or no practical use, whatever their value as the germ of this or that mechanical principle.

The "true and first" inventor of the mechanically propelled carriage, so far as can be ascertained, was Captain Nicholas Joseph Cugnot, of the Artillerie Française, whose steam trolley was designed for the carriage of cannon. This was constructed in 1769, and consisted of a three-wheeled vehicle, the front wheel of which was used both for driving and steering; although, as results turned out, it utterly failed in the latter capacity. The power was derived from steam supplied by a globular boiler and furnace; which with the double-cylindered engine and driving mechanism, were supported in a supplementary frame over and round this front wheel. The connecting-rods from the pistons were secured to panels working in ratchets on the axles on either side of the wheel, the reversing being effected by changing the pawls over to the other side of the notches on the ratchet wheels. But it was this placing of the boiler that practically caused the failure of the invention, which nevertheless succeeded in carrying a load of some 2½ tons at a speed of nearly three miles an hour, despite perpetual halts to get up the necessary working steam-pressure. Cugnot realised, of course, that attaching the boiler to the main frame would have involved the use of telescopic—or at least elastic—steam connections. These would probably have leaked badly, or been torn off outright. Therefore he placed the boiler forward of the front wheel, the practical result being that the whole affair became too top-heavy to steer; failing in this respect as badly as if all the wheels had been rigidly attached to the frame after the fashion of a railway truck. Had he, on the other hand, placed his boiler and engine at the rear of the frame, connecting the driving mechanism to the rear-axle and leaving the front wheel free for steering purposes, road locomotion by steam might have been achieved half a century earlier. Nevertheless, to Cugnot must be ascribed the honours of the pioneer; and it is interesting to note that his ratchet-and-pawl system of power transmission was copied more or less closely by most of his successors during the next two generations.

The first practical steam-propelled vehicle was, however, the one patented in 1802 by Trevethick and Vivian. On this the crank-shaft was fitted with a flywheel, and geared to the driving-wheels. Off and on this machine ran for the next three years, actually maintaining an average speed, it is said, of ten miles an hour! Indeed, so successful was it, that had not its inventors suffered by the too common fate of such, in coming to the end of their money, there is every reason to suppose that the railway engine would not have forced into the background the whole matter of self-propelled traffic on the high-road during the next half-century. It must be remembered that the great point in favour of the steam road carriage was the enormous improvement in the roads themselves—to a degree little short of their present condition—which had been brought about by the great increase in the number of stage coaches during the decade or so prior to 1802, by the invention of road-paving by Macadam, and by the inauguration, in later years, of the turnpike system. There can be no doubt that all the circumstances were ripe for the success of the steam carriage, which in this instance, however, was hindered for the lack of a few pounds.

Nevertheless, the ideal of the self-propelled carriage was by no means lost; though it was undoubtedly hindered by the fallacy which prevailed until about 1825, that the "sticktion" or grip of the wheels on the road surface was insufficient for purposes of traction. Later on, of course, this idea was exploded by the railway; but in the meantime, when much useful work might have been done, inventor after inventor wasted his time with one and another device of which mechanical imitations of the action of the legs and feet of horses were the principal features. Indeed, the idea seems to prevail to this day that such imitations are likely to be of value for heavy traction.

At last, however, in 1828 Mr. (afterwards Sir) Goldsworthy Gurney patented a steam coach, with a boiler behind, and an engine beneath, the piston of which was connected by a rod to the hind-wheels. This coach was also partially steered by a fifth wheel in front (hence probably another well-known phrase), but judging from old diagrams, the fore-carriage could be turned in either direction. Three years afterwards, Sir Charles Dance established a service of Gurney steam coaches between Gloucester and Cheltenham; which, running four journeys daily, carried 3,000 passengers and ran some 4,000 miles up to the end of June in that year.

Then, in 1833, came Walter Hancock's steam omnibuses; but although these vehicles were well tried in London in 1836, they were anything but a commercial success; albeit far in advance of other inventions during Hancock's period, such as those of Colonel Maceroni and his partner Squire, Gibbs, Dr. Church, J. Scott Russell, and Hills of Deptford. But the reasons for these failures are not far to seek, when it is remembered that at this period horse-drawn vehicles had well-nigh reached their highest stage of speed and general efficiency; whereas all the above machines were noisy to a degree, cumbrous, slow, expensive to repair and maintain, and continually breaking down owing to their great weight and crude construction. Consequently they by no means exhibited that promise which we, in the light of later developments, are justified in considering they possessed. On the other hand also, in point of construction, it must be remembered that steam, and, consequently, almost the whole art of mechanical engineering, were then in their infancy. Few stationary steam engines had been built even, so that it may be said that the smith in the various branches of his trade was practically the only mechanical engineer.

Yet it was perhaps these disadvantages of great weight and crude construction that furnished, more than anything else, the pretext for that ill-considered legislation which, beginning with the Locomotive Act of 1836, and continuing until that iniquitous measure was repealed only seven short years ago, has been permitted by the short-sighted representatives of the people of Great Britain to enmesh their country and its commerce in a network of legalised tyranny and spoliation for which there is hardly a parallel in the history of civilisation; the result being that the industry was crushed out of commercial existence in Great Britain until 1896.

Nevertheless, we do not find that it had been any more fortunate on the Continent; for although Cugnot's trolley had certainly been made to run after a fashion, its failure from a practical standpoint was so pronounced that the whole question of auto-propulsion was neglected for the next century. Nothing, in fact, of the slightest importance in this line was produced in France during that period, with the exception of Pecqueur's steam waggon in 1828. This, however, was important in an academic sense, as it embodied certain principles of construction which are retained to a great extent in the modern motor-car. In the first place, Pecqueur's machine was the first to have a differential gear; this being a planet-gearing which served to connect the two halves of the rear-axle. Then, secondly, the axle-arms of the front wheels were pivoted vertically in much the same fashion as is now in vogue. It is true that they had little or nothing to do with the steering of the waggon; being merely interconnected to keep the wheels parallel, the steering being effected by the pivoting of the fore-carriage. But the device was at least there in its entirety as now used; albeit its full possibilities were neglected at the time.

Unquestionably the great continental revival of the automobile idea was due, not only to the absence in France and Germany of those tyrannous restrictions under which its British protagonists laboured, but primarily to the invention of the compression type of internal-combustion motor by Alphonse Beau de Rochas, whose physical laws, as laid down in his pamphlet of

1862, in regard to these engines remain constant to this day, and will probably do so for all time. Here it cannot be too firmly insisted upon that the late Dr. Otto, whose name is generally attached to the four-stroke cycle, had nothing to do with its invention or even its development. Beau de Rochas was so far in advance of his time that he was never encouraged, financially or otherwise, to build a single engine, and so allowed his patent to lapse. Otto, on the other hand, had the most trustworthy financial support from his partner, Geheimrath Langen. Yet after fourteen years of failure with engines of the non-compression type he adopted Beau de Rochas' principles in their entirety, the result of this "discovery" being the Otto-Silent gas engines. Nevertheless, it redounds to the credit of the French nation that they at least have consistently recognised Beau de Rochas' priority, and that he was awarded — albeit by a private learned society—a pension for his services to science. To a lesser extent may the honours of the pioneer be claimed for Lenoir, who in the same year, 1862, is known to have used a mixture of coal gas and air to drive an engine—of the non-compression type that still bears his name—which was the first ever mounted on a road car. This car ran a few trips, it is said, between Paris and Joinville; but as its engine was not only heavy, but complicated and unreliable in respect of its ignition, and, furthermore, only worked at one hundred strokes or so per minute, it may be regarded as a total failure for automobile purposes.

Meanwhile, in Great Britain, we find the endeavour to produce a light steam-propelled road carriage still persevered with, the rate of production being about one a year during the next fifteen years. Yarrow and Hilditch brought out one such vehicle in 1862, and S. G. Rhodes another in the following year, after which a lapse of three years occurs before H. P. Holt built his steam locomotive. Then 1868, 1869, and 1870 witnessed the building of steam carriages by J. H. Knight, Catley and Ayres, and L. J. Todd.

In 1868, too, Pierre Joseph Ravel invented the first petroleum burner, which was designed to use the residue petroleum or "massout," then being practically sold as a waste product after the ordinary lamp petroleum had been distilled from it. This burner was used to heat the first water-tube boiler; which, with a light 3 h.p. engine, was installed in a very practical light road steamer. We find, however, as Ravel's was the solitary continental attempt in forty years to solve the problem of road-locomotion—whereas the idea had never been allowed to die out entirely in Great Britain—another proof that British engineers were in reality far more enterprising throughout than their continental contemporaries, who laboured under no restrictions of any kind.

We have next C. Randolph's road locomotive in 1872, R. N. Grenville's and H. A. O. Mackenzie's in 1875, and Blackburn's in 1877. Also, in this last year, Thompson's steam carriage, which is chiefly notable for the fact that it was the first to have indiarubber tyres. Here, again, we see British engineers in the light of original inventors, whose devices were practically shorn of most of their value (for lack of commercial scope) owing to the monopoly-upholding laws of their own country. Nevertheless, it must be admitted that none of the steam carriages above mentioned represented any great advance upon earlier creations. And although James Robson (in 1879) and Dugald Clerk brought out their respective two-stroke engines in and before 1881, and were followed a few years later by Joseph Day, of Bath, the state of the law practically precluded the application of any of these devices to the auto-propulsion of road vehicles, even when three years later the use of petrol or benzine (to produce an inflammable gaseous mixture) became known. Thus the two first-named engines were employed for stationary purposes only, while the later invention of Day could only be further adapted to marine work.

Consequently, while British engineering enterprise was fettered, it was reserved to Delamare-Deboutteville and his partner, Malindin, to become, in 1884, the fathers of modern automobilism by inventing a carburettor which, using petroleum spirit, enabled a small internal-combustion motor to drive the first motor-tricycle ever run on a public road. Undoubtedly, the priority is theirs; but their honours in that respect admittedly pale before those of their successor — by a few months only—the great progenitor of the modern motor-car engine.

This was Gottlieb Daimler; who, born in 1832 at Schorndorf, a small village near Wurtemburg, may truly be said to have begun his distinguished career at the budding of one branch of his art, witnessed its bourgeoning, and having grafted a shoot therefrom, lived to see that shoot exalt itself above its parent branch before he closed his career beneath its shade. From a child he exhibited an astonishing aptitude for mechanics, so that his choice of the engineer's trade whilst still a mere lad was merely in accordance with the fitness of things. During his *wanderjahre* as a journeyman he gained experience at most of the leading engineering works of his native land; but as at that period German engineering craftsmanship had little of its present merit, it was only to be expected that he would seek a higher standard of training. This he knew could only be obtained at that time in Great Britain, which had now become the world's manufactory; so we next find him spending several years at Whitworth's, where he acquired that knowledge of practice, accuracy, and finish to which, almost as much as to his own genius, most of his success was due.

Returning to Germany in 1871, he became associated —quite by chance—with Dr. Otto and Geheimrath Langen, who had already spent several years in gas-engine experiments. The outcome of this meeting was the opening, in 1872, of the Gas Motoren Fabrik at Deutz, near Cologne, for which enterprise Herr Langen found the money, while Daimler acted as works-manager. Lenoir's non-compression gas engine by this time was losing whatever credit it had had; and Beau de Rochas' principles, though known for the past ten years, had been utterly neglected. It is therefore more than likely that the young works-manager, keen to recognise the uselessness of persevering in the face of the repeated failure of Lenoir's methods, was the real author of their abandonment and the adoption of compression principles by the Gas Motoren Fabrik firm in 1876. Be this as it may, he left the firm to assist and advise Crossley Bros. in the manufacture of their now well-known oil engine; and, again, it is more than probable that the experience thus gained led him to investigate the theories of, and generally specialise, oil engines in preference to those using coal gas, recognising that the former had a wider commercial scope than even the compression gas engine of the type then being manufactured by Otto and Langen, whose works at Deutz, even up to 1882, were hardly paying their way.

In the previous year, 1881, we, nevertheless, note one slight contribution to auto-propulsion, namely, M. Raffard's electric tricycle, which is merely of historical interest as the first electric vehicle. Its successor, however, did not appear until twelve years later; so electrical possibilities could hardly have been so apparent to Daimler—to say nothing of being out of his line—as those of gas or inflammable vapour production from the lighter petroleum products, which the progress of industrial chemistry had long since placed at his disposal. We therefore find him, during the long gap between his leaving Otto and Langen and the date of his first patent, in retirement at Mainz, experimenting with various compression engines and petroleum fuels. What led him to turn his attention to mechanical propulsion for vehicles does not appear. But it was probably the success of Delamare-Deboutteville and Malindin, in the year 1884, in which he took out his first patent. In the following year, however, he made a small motor and fitted it to a bicycle of the old hobby-horse pattern, recognising, no doubt, that the "ordinary" then in vogue was unsuitable for such work. Now had Daimler been an inventor of the ordinary type, it is only too likely that he would have been so satisfied with the measure of success thus scored that he would have turned all his attention to bicycle motors, to the incalculable loss of automobilism. But Carl Benz, of Mannheim, had patented a two-cycle engine in the previous year, and fitted it to a three-wheeled road carriage. And as these things never lack publication, it is more than likely that Daimler (whose practical experience with the four-stroke engine was then second to that of no living man) would see that the latter type of motor held, for the present at least, far greater possibilities for carriage propulsion; especially since Benz's first engine was not a shining success.

In 1886, therefore, he constructed his famous V-shaped twin-cylinder engine, the fuel of which, as with his previous motor, appears to have been benzine supplied from a surface-carburettor. This he installed aboard a launch. Of course he may have been inclined to do this owing to the enormous demand that would arise (and has since arisen) on the continental waterways for a reliable and compact marine engine. The Paris Sailing Club had held steam-launch races annually for the past nine years, and in 1884 over £400 had been given in prizes for similar events at Nice. But, on the other hand, it is far more likely that he considered that marine work, because of the constant character of the load, would afford a far better initial test of this engine —the largest of the kind he had as yet constructed— than he could obtain on a road vehicle. That his tests were satisfactory we may be assured, for he applied his engine to a car for the first time in 1887, and during the next two years, it is said, built some fifteen others, besides several engines, which were installed in launches.

But it was from his sale—through another chance meeting, it is said—of his French patents to M. Sarassin, of Paris, in 1888 or thereabouts, that the dawn of modern automobilism may be said to date. This gentleman, doubtless, foresaw the industrial future of Daimler's type of internal-combustion motor, and had several manufactured for sale, under the superintendence of the latter, at various Paris works; among which were those of MM. Panhard and Levassor, the successors in the Perin business of bandsaw-making and general engineering. Nevertheless, M. Sarassin died a few months later, and his widow, knowing nothing of the technical details of the motor-manufacturing business, entrusted it entirely to M. Levassor. Twelve months later she married him, throwing in the above-mentioned patents as part of her marriage portion. Out of this marriage, then, and the subsequent exclusive manufacture under Daimler's patents by MM. Panhard and Levassor, arose the industry which has arisen in twelve years to an annual value of several millions sterling. But this industry, had it not been for the sheer imbecility of a single statute, might rather have arisen on British soil; for it has been credibly stated that Daimler's meeting with M. Sarassin was mainly due to his returning, *viâ* Paris, from a visit to this country, during which he had endeavoured in vain, despite his extensive acquaintance in British engineering circles, to induce a single firm to purchase his manufacturing rights.

But as it happened that, owing, on the one hand, to the lapse of Beau de Rochas' and other four-stroke patents, and on the other, to the existence of Robson's and Clerk's for two-stroke engines—there could be no sustainable continental patent for an internal-combustion motor of either type merely as such, nor even for its application to vehicles, but only as to *improvements*, it is not surprising that there were others in the field, such as Benz, Tenting—the modern pioneer of electric ignition—Amédée Bollée, and Gautier; to say nothing of Leon Lefebvre and Seck. Yet when Daimler's labours during the eleven years prior to 1895, and his nine separate patents relating to motors taken out during that period, are taken into account, together with his long association with Panhard and Lavassor, and afterwards with Carl Maybach, of Caunstadt, near Stuttgardt, it will be readily admitted that there are few honours of the pioneer of automobilism that may not justly be ascribed to him. Other names, however, which are none the less indelibly written in the history of this golden age of invention, beside those already mentioned, are those of Les Fils des Peugeot Freres, De Dion and Bouton, Mors, Lepape, Delahaye, Jeantaud—the pioneer of the electric automobile—Roger, Kane of Chicago, and Serpollet.

We note, however, that Panhard and Levassor have practically improved Daimler's engine out of all resemblance to its original, and even its later form; the only feature retained being that of height, so far as design goes. Indeed, it would be difficult to imagine any two engines of the same genus differing more widely in design than Daimler's original V-shaped motor and a Panhard "Centaure" of 1903; or than the former and its successor, the Mercedes-Daimler. Similarly, even the second Benz (four-stroke) motor has long been rendered obsolete by the improved engines made by the Mannheim firm, by those of Durkopp, and several others east of the Rhine. In fact, change and rechange in design have been constant throughout every one of the nineteen years since Daimler's first patent was taken out; and it may be said that Tenting's employment of electric ignition in 1887, though neglected for many years after, has been responsible as much as any other factor in the case for many of these changes, so far at least as combustion-chamber and general cylinder-head design is concerned.

Yet among all the names mentioned above there is none whose engine has exercised a greater influence on general design than the Pygmée motor of Leon Lefebvre. Its compact and (at first sight) somewhat squat appearance, its large, accessible crank case, and, above all, the simplicity of its construction and working, have furnished the model (not, of course, through slavish imitation, but either directly or indirectly, as a matter of "the best-known practice") for practically all the leading vertical four-stroke motors of the marine type in Great Britain, on the Continent, and in the United States. And, with modifications in detail, the same may be said for a considerable number of the best-known automobile engines on both sides of the Atlantic, such as the "Abeille" motor of Dalifol; those of Rochet-Schneider, de Dietrich (Turcat-Mery); the Aster, and the F. I. A. T., of Turin; the Humber, Maudslay, Blake, and Standard Co., of Coventry, in Great Britain—the last bearing a remarkable resemblance to the Pygmée in its lower parts—and the engines made by the Buffalo, Clifton Motor-Vehicle and Power Co.'s, and many others in the United States. All these, it is true, differ widely in detail, but in their general outline, whether unconsciously inspired or not, the influence of Lefebvre's original design is distinctly traceable.

Similarly Amédée Bollée's motor was the precursor of all engines of the horizontal type which lie lengthwise in the frame of the car, just as Henriod's engine undoubtedly was of all those with opposed horizontal cylinders lying transversely in the frame, with the exception of those in which each pair of cylinders has a common combustion-chamber lying centrally between each pair of pistons. It must, however, be understood that not only have all the original continental motors previously named been subjected to alteration in detail—often of the most radical character—almost every year since the latter eighties, but also that during that period dozens of new firms have sprung up with still other improvements. Thus it becomes quite as difficult to determine whether or not any modern engine is a combination of the characteristics of its predecessors as it is to trace the influences which have led to its design. Many modern makers also have not only introduced new patented improvements of their own, but have secured licences to combine other patents in an entirely new engine, which as a result has proved more efficient. And it must be admitted that such procedure is highly favourable to the interests of automobilism, for without losing sight of the value of original research and invention, there can be no doubt of the merit of a good combination of other people's ideas that have been thoroughly tested. Indeed, it requires almost as much talent to create such a combination as to invent any one of its component parts.

CHAPTER II

MODERN PERIOD

THE foregoing apparent digression from the historical to the technical side of automobilism has been advisedly introduced at this juncture, because the early nineties—as has been shown by the subsequent history of automobilism—practically separate the period of the invention of the various types of motors and their application to road vehicles from the period of their improvement and development generally. In fine, that era separates ancient from modern automobilism, for with the exception of the compound petrol-electric motor and one other, no new method of applying mechanical propulsion to road carriages, other than bicycles and the like, has been devised since then. On the other hand, the efforts of inventors have been almost entirely concerned with the improvement of existing motors and methods of applying them. Subsequent history, therefore, has mainly to do with mechanical changes in detail, and with the long-distance road-racing tours and trials that have contributed so enormously to the improvement of motors and vehicles alike, and to the growth of modern automobilism. Thus it follows that a definite reference to the various types of motor available at the beginning of the modern period is not only appropriate, but historically necessary.

This era—1889 to 1896—is also singularly important from another point of view, since it represents the period in which British engineers were supplanted—at least temporarily—in an industry which, as has been shown, they had made peculiarly their own, which they had kept alive by consistent effort, and in which they had ever been the foremost (and for a whole century the only) protagonists and pioneers. But their continental rivals were encouraged to develop the automobile industry, and to support financially any likely invention, by the fact that they laboured under no obsolete and ridiculous laws restricting road-locomotion, had the best roads in the world to experiment upon, and furthermore an assured home market as well as the prospect of an equally remunerative market abroad.

Thus while British engineers were deprived of the fruits of a century's consistent endeavour, their French and German contemporaries were hard at work inventing, experimenting, and improving their motors and motor-vehicles until, at the beginning of 1894, the automobile, though not in general use, and still regarded by the public as an unreliable and costly vehicle, was by no means an uncommon sight in the streets of Paris. Several scores of them were already in use, but hitherto no public demonstration of their capacity to make a long journey without breaking down had been made. The manufacturers and *cognoscenti* generally, we may be sure, had very few doubts on this score; and readily responded when, in July of that year, the proprietors of *Le Petit Journal* offered prizes for the winners of a long-distance road-race, the first of any kind in the history of movement. The route chosen was from Paris to Rouen and back; and of the score or so of competitors more than two-thirds succeeded in completing the journey without a breakdown, and at an average pace equal to that of any horse-drawn vehicle.

The two winning cars were driven by the late M. Levassor and by one of the firm of Les Fils des Peugeot Freres, who divided the first prize. The success of this event created no small excitement, for it had at last been unmistakably shown that the new locomotion was not only speedy, but safe and reliable. It was not, however, until the following year, when the race from Paris to Bordeaux and back had scored an even greater success, that the French automobile industry really began to flourish, and to attract the attention of capitalists who had no particular knowledge of engineering, but were in search of a sound industrial investment. Yet, to the credit of all concerned be it said, caution and moderate capitalisation were the dominant features of the financing of French automobile concerns. Had a like policy been followed in Great Britain a few years later, it is probable that our own automobile industry would long since have overtaken its continental rival.

Some thirty vehicles competed in the Paris-Bordeaux race, which M. Levassor won outright, finishing over an hour ahead of his nearest competitor. Two other Panhard-Levassor cars were among the prize-winners, three Peugeot cars, two manufactured by M. Roger, and one Bollée, driven by M. Amédée Bollée, second of that famous name. M. Levassor drove the whole distance of 744 miles in 48¾ hours, his speed frequently equalling 20 miles per hour, and was not apparently unduly fatigued by the journey; for after partaking of light refreshment, he waited several hours at the finishing-point to see the rest of the competitors arrive. A few weeks later the first endurance trial ever held in America took place between Chicago and Waukegan. In this event several steam cars competed; but owing to the roughness of the roads less than half a dozen of the competitors, it is said, completed the journey. American automobile manufacturers, however, in November of last year, carried out an endurance trial, in the run from New York to Pittsburg, that not only wipes out the memory of any previous failures, but stands—and will long continue—unparalleled in the history of automobilism. This not only, again, because of the sheer stress of the climatic and road conditions which persisted throughout, but because—despite the fact that all railway and telegraphic communication had ceased on account of the violence of the weather—one-fourth of the cars engaged actually kept their scheduled time and twenty out of thirty-four starters finished.

The year 1894, however, is chiefly memorable in the British history of the movement on account of the importation, by Mr. Henry Hewetson, of the first car driven by an internal-combustion engine ever seen in the country. This was a 1½ h.p. Benz car, with two speeds and electric ignition; the latter being rare at that time, as tube ignition was almost universal. Then, in the following year, the Hon. Evelyn Ellis imported a 4½ h p. Panhard and Levassor, and began with a "non-stop" run from Micheldever to Datchet, with his friend Mr. F. R. Simms aboard as guide, philosopher, and mechanician. Yet though both he and Mr. Hewetson drove their cars for many a day thereafter much faster than the four miles an hour then imposed upon all mechanically propelled road vehicles, and totally dispensing with the equally statutory man with a red flag, they were never interfered with by the rural policeman; whose natural common sense had not, at that date, been perverted by his official superiors. In October of the same year, 1895, a still more important event took place, this being a semi-public demonstration by Sir David Salomons of the capabilities of another Panhard-Levassor car. Fully 10,000 people were present, few of whom, we may well suppose, had any idea of the growth which automobilism was to assume within the next eight years, or of the scope which lay (and still lies) before the motor industry.

On the 2nd of the following month Mr. Henry Sturmey, M.I.C.E., F.R.P.S., of Coventry, established *The Autocar*, the first English journal exclusively devoted to the interests of automobilism; and before the year was out, Mr. F. R. Simms, who had long been associated with Daimler professionally, purchased the latter's patents for Great Britain, and founded the first British motor manufactory; that is, the first in which internal-combustion motors were made for automobiles. From this year 1895, then, the age of modern British automobilism may be said to date.

In 1896 further proof of the progress of automobile construction was forthcoming, in the September race from Paris to Marseilles and back, in which over thirty vehicles started and fourteen finished, as against nine in the Paris-Bordeaux event the year before. The average speed for the whole distance of 1,063 miles of the winning car—a Panhard-Levassor of 4 h.p. only—was about 25 miles per hour. Two other Panhard-Levassor cars and a De Dion-Bouton, also of 4 h.p. each, were second, fourth, and third respectively, the highest-powered vehicles in the race being two Peugeots of 6 h.p. each. The lowest average of miles per hour in this event was over 12¾ miles, by a Michelin-Bollée, thus showing the marked improvement that had been made in fifteen months only. Reverting to the movement in Great Britain, it is not astonishing to find that no progress of this particular kind had been made, seeing that the Locomotives upon Highways Act of 1831 was still in force. Nevertheless, some two score cars—nearly all of which were of foreign manufacture—were running on English roads; and Mr. F. R. Simms had established his second claim to be called the father of modern British automobilism by founding the Motor Car Club—now the A.C.G.B.I.—to promote the interests of automobilism, and for social purposes generally.

The third of Mr. Simms' many undisputed claims to the above title is, that no sooner was the Club founded than he and its other influential members, among whom were Sir David Salomons and Mr. H. J. Lawson, set to work to promote legislative reform with such success that finally the Magna Charta of the British automobilist—the Light Locomotives Act—was passed, and came into operation on November 14th, 1896. This event was celebrated by a run from the Club's premises, in Whitehall, to the Hotel Metropole, Brighton, some thirty-five machines, including motor-cycles, starting, twenty-two of which reached their destination that night, but only thirteen in time for the commemoration dinner. So far as can be ascertained, no official observation, such as would govern the most unimportant trial nowadays, was in force, the motive inspiring all concerned being to get through as best they could. In fact, many and fearsome were the adventures experienced with most of the successful twenty-two cars,

good luck quite as much as any particular constructional merits they may have possessed saving the majority from the fate of the odd dozen that failed to get much beyond the Metropolitan area.

The year 1896 has already been mentioned as the date of the application, by L. Eppstein, of London, of the compound petrol-electric motor to road vehicles. The only other exception to the statement previously made to the effect that novelty of application ceased in the latter eighties also occurred in this year. This was the invention, by Pretôt, of the *avant-train*, or motor fore-carriage, that is to say, a motor complete with cooling system and other connections, mounted on a pair of front driving-wheels, the whole device being substituted at will for the fore-carriage of an ordinary horse-drawn vehicle. Variations of this system have since been introduced by Riancey, Amiot-Peneau (Augé motor), Ponsard-Ansolini (Roser-Mazurier), Doré, E. Lockert, Emile Salles, Johnson, of Chicago, and latterly Collin (de Dion). But for some reason, despite the undoubted efficiency of the majority, and the commercial value of the idea, they have not found favour with any section of the public, although one would imagine that they would ere this have obtained an enormous vogue among jobmasters and cab proprietors. The latter, apparently, can hardly be fully awake to their own best interests, or they would see that the motor fore-carriage represents their only chance of meeting the modern demand for a reliable hired automobile without sacrificing any of their existing carriage stock; one, furthermore, which they might use alternately with their horses—much to the benefit of the latter—until these again were unfit for further service.

So much for the practical results of 1896; but so far as Great Britain was concerned, the history of the next two years may be described as a mingling of tentative effort, unbacked by necessary capital, contrasted with spasmodic and technically unskilful effort on the part of those who had been entrusted with only too much money; of over-capitalisation, failure to realise either dividends or any practical result, and a general air of uncertainty of purpose, all of which circumstances handicapped the infant industry in the most fatal fashion. Then, again, lack of actual personal experience in this branch of engineering even among the otherwise technically qualified (which lack, of course, was the direct outcome of previous legislative restrictions), compelled the few who had taken up automobile construction to take every detail of practice at second hand from the Continent. One can readily imagine, however, that had our marvellous British patent laws compelled foreign patent-holders to manufacture in this country or grant manufacturing licences (under penalty of voiding), this state of affairs would probably have been ameliorated, and the French priority in automobile construction would have lost half its effect. Indeed, on account of the smaller cost of material prevailing in Great Britain, the seat of the industry might even have been shifted hither. Still, the road test at speed—the secret of half the continental success then and during the next six years—was lacking; indeed, such a test is still illegal, and was only permitted on one occasion last year by a special Act of Parliament!

Therefore, while British engineers stood bound and shackled, their continental compeers, fostered and encouraged in every way, were building lighter and more efficient, if not much more powerful motors; and lighter, stronger carriages. This is shown by the fact that the average speed of the winning Leon Bollée car in the Paris-Dieppe race of July, 1897, was over 40 miles, while that of the slowest of the sixteen vehicles that finished was a mile and a half faster than that of the winning Panhard-Levassor car in the previous year's race; albeit the distance was only about a tenth. Still, of these sixteen, eight had motors of 6 h.p., while three had 5 h.p, and one 3 h.p., the remainder being tricycles with 1½ h.p. motors. Next year, in the Paris-Amsterdam race, not only were eight of the dozen cars that finished fitted with 8 h.p. motors, but the winning Panhard-Levassor car made an average time throughout the 950 miles of nearly 45 miles per hour. The fastest of the motor-cycles—a 1¾ h.p. de Dion-Bouton—also averaged over 36 miles an hour.

Nor had the commercial vehicle been neglected during these two years, for trials of heavy vehicles, omnibuses, lorries, and vans were held at Versailles, in which steam (with both coke and liquid fuel), the petrol motor, and electricity were well represented, 35 h.p. being the highest among the first type, 14 h.p. the average with the petrol division, and an average useful load of 650 kilos. the capacity of the two electric vans shown in 1898. Still, the 6 h.p. Leyland steam brake which competed this year made a fair showing, carrying perhaps a heavier load for its horse-power than all but one or two of its competitors. At Liverpool, too, in May of the same year, it was seen that British builders, though temporarily behindhand in autocar manufacture, could at least hold their own in the commercial section; for five steam waggons competed, one of which, sent by the "Lifu" Company, carried a load of something over two tons at a speed above 8 miles an hour, with a consumption per ton mile of ·298 gallons, at a cost of 1·2*d.* per ton-mile for fuel.

The next year (1899) witnessed a further increase of horse-power and speed, both in the second Paris-Bordeaux race in May and the Tour de France—1,386 miles—barely six weeks later, the winning Panhard-Levassor cars—of 12 and 16 h.p. respectively—making averages of 48 and 51 miles per hour. These two tests, however, despite the uniform good quality of the French roads, were exceptionally severe, so much so as almost to revolutionise car construction for the time being at least. Hence the following year was rather a *reculade pour mieux sauter*, so far as the road-racing side of automobilism was concerned. But it was clearly recognised that the average tare weight of cars was too heavy, and that equally good results could be achieved, with about half the cost in tyre maintenance, by a light car of moderate horse-power, either for racing or touring. As a result, no less than fifteen of these finished in the Paris-Bordeaux race of 1901, a Panhard and a Darracq arriving sixth and eighth respectively out of the twenty-eight competing. Meanwhile, in Great Britain, although little real progress had been made in car manufacture—mainly owing to over-capitalisation and lack of definite aim, experiment rather than systematised production being the order of the day—the heavy-waggon branch of construction made fair headway; indeed, quite kept pace with continental manufacture. And the various hill-climbing and endurance trials promoted by the Motor-car—now the Automobile—Club, although composed in the main of continental imported cars, afforded the most valuable object-lessons in design, construction, and other technical matters that British manufacturers could possibly have had.

The great Paris-Berlin race of 1901, however, showed the revolutionary nature of the change in construction that had been effected. Horse-power had increased with a bound, no less than fourteen of the heavy cars having 28 h.p. engines, and one—the Mercedes car, sent out by the Canstatt-Daimler firm—having one of 35 h.p. The average speed of the winner—a 28 h.p. Mors—was again over 50 miles per hour, not including neutralisations, over the 749 miles; while that of the half-dozen light voiturettes which got through was well over 25 miles per hour—one, a Renault of 7 h.p., averaging more than 38½ miles. Altogether forty-three cars finished; but so many were the temporary breakdowns through constructional failure, that it was recognised, as much by the manufacturers themselves as by the public, that the battle of reliability was by no means won as yet. In September of the same year, however, gratifying evidence of the growth of the manufacturing industry in Great Britain was forthcoming in the run to Glasgow arranged by the A.C.G.B.I. Nineteen British concerns were represented among the entries, and twelve British-made cars actually appeared out of a total of twenty-five. Of these, two—the Napier and Argyll cars—were the only ones that succeeded in scoring the maximum of marks on the run, *i.e.* 1,500.

In April of 1902 the Earl of Suffield gave permission for a series of speed and hill-climbing trials to be run at Suffield Park, Cromer. In these, which excited great public interest, a Napier car of 50 h.p. scored the highest marks for the four runs—two up- and two downhill—the speed recorded being over 48½ miles per hour on the second uphill climb. Yet in view of the fact that its nearest competitor, a Mors, had only 24 h.p., while the other seventeen, ten of which were British made, ranged between 7 and 16 h.p., we can hardly regard these results as conclusive. Indeed, by the published figures, it many be seen that, horse-power for horsepower, the greatest efficiency was shown by the little 4½ h.p. de Dion voiturette, the 10 h.p. Panhard coming next. At least, this is the conclusion to be arrived at from the marks obtained. Nevertheless, regarded as speed trials in which victory rested with the biggest power, the result was encouraging, especially as the Napier Co. had entered a 60 h.p. (nominal) car in the Paris-Vienna-and-Gordon-Bennett Cup race two months later. No less than eighty-four cars—among which were six Panhards of 70 h.p.—completed the three stages in which the race was run; but the mistaken policy of running the two events on the same course, and at the same time; and the fact that the Gordon-Bennett contest was considered of so little comparative importance that the first twenty cars which reached Innsbruck ahead of the Napier had not been entered; shows the latter's victory in an entirely false light, well though it was deserved. Nevertheless, beside winning the Gordon-Bennett Cup, the Napier car finished eighth in the major contest without a breakdown of any kind; a feat which, considering that the pace on many portions of the route exceeded 60 miles per hour, shows that Great Britain had at length drawn level with the Continent in the production of a speedy and reliable automobile.

No British cars took part in the Circuit des Ardennes of July, 1902, manufacturers being more profitably absorbed in preparing for the A.C.G.B.I. hill-climbing and reliability trials two months later. In these eighty-eight cars competed, twenty-six being of British make. Only two of the latter, however, an M.M.C. voiturette of 8 h.p. and a 12 h.p. Daimler, actually scored top marks in their respective classes, but the placings were extremely close. Last year was perhaps the most sensational in the annals of automobilism, the list of casualties which occurred during its earlier months threatening the very existence of racing in any shape. First, Count Elliott Zborowski was instantly killed, his amateur mechanician, M. de Pallange, seriously injured—it is believed permanently—and his car smashed into a shapeless mass, while negotiating, at a speed of near 70 miles an hour, a notoriously dangerous double curve near the crest of La Turbie Hill; which for the past three years had been the course of an annual hill-climbing competition during Nice automobile week. This sad event occurred at the beginning of April; but worse was to happen, barely eight weeks later, in the great road race from Paris to Madrid. Out of some two hundred vehicles that started only forty or so got through to Bordeaux, where the race was stopped. M. Marcel Renault was killed instantly, as was also Mr. Nixon, who was acting as mechanician on one of the Wolseley cars. Mr. Loraine Barrow—an American artist who had latterly become well known as an amateur racing automobilist—received such terrible injuries that he died in a few days; and amongst the other drivers several were more or less seriously hurt.

Such was the sensation aroused by these tragic occurrences that for a short period it seemed likely, not only that the Circuit du Nord would be prohibited, but even the Gordon-Bennett Cup race; which was to be held on British soil for the first time, and had now become an event of first-rate importance. But when the truth was realised that the Paris-Madrid disaster was caused, first, by the go-as-you-please scrambling nature of the contest and the fact that it was practically a point-to-point race; secondly, by the lack of control which permitted spectators to stray about the course *en route;* thirdly, because no attempt had been made to lay the dust or prepare the road; and, fourthly, because the dust-cloud raised hid dangerous points which were but carelessly indicated in any case—wiser counsels prevailed, and it was seen that the fault lay not in road-racing itself, but in the manner in which it had been carried out. The Circuit was therefore allowed to take place as usual, and the fact that it had hitherto been notably free of accident brought out the chief characteristic of such a course in the strongest light; namely, that with good organisation and an ordinary amount of precaution, a circuitous course can be policed and made safe for competitors and spectators alike, in a manner well-nigh impossible with a long point-to-point route. As it turned out, only one accident occurred, this being that one of the occupants of the solitary British car—an 80 h.p. Star—fell out and broke his ankle. Yet this car was going quite 80 miles an hour at the time, and up to that moment had every chance of winning.

But the truth of the above became still more evident in the July race for the cup, which was held on a double-circuit course in the neighbourhood of Ballyshannon, co. Kildare; for, beyond the overturning of one of the Napier cars, driven by Mr. Charles Jarrott, the breakage of a wheel on Mr. Stock's Napier, and various constructional troubles sustained by the Napier car driven by Mr. S. F. Edge, as well as by the American cars, it is safe to say that not a sovereign's worth of damage, still less anything approaching a casualty, occurred to man, woman, child, or animal throughout the whole Irish Fortnight. Thus the character of automobile racing as a sport which, properly controlled, is not more productive of danger than many others commonly indulged in, was thoroughly rehabilitated. But what was demonstrated beyond question was that, in ordinarily skilled hands—that is, those competent to drive it at all—an automobile weighing a ton and capable of a speed greater than that of an express train can be controlled and stopped dead with greater ease and in less space than a dogcart drawn by a horse at a 14-mile speed.

The actual racing results of the great Irish event of 1903 are too fresh in the public mind to need recapitulation. Nor is there much profit in discussing the might-have-beens of the matter, had the Wolseley and Star racing cars been afforded an equal share in the representation of this country. But the Phœnix Park, Castlewellan, and Cork trials, which were after all equally important events of the Fortnight, made it abundantly clear that British engineers have at length proved equal to their continental contemporaries in building a speedy, light, powerful, sound, and durably constructed automobile. This has been confirmed, furthermore, in trials of still more recent date, which also, for the reasons above given, need not be recalled in detail. And lastly, the three exhibitions lately held at the Crystal Palace, the Agricultural Hall, and the Salon d'Automobile have shown, first, that British motor-manufacturing practice is not only equal, but in the opinion of many good judges, superior to the best continental; and, secondly, that in the construction of the light car of moderate power—the automobile of the future—Great Britain at length leads the world.

British motor-engineers, however, have done still better in regard to those even more important branches of construction, the heavy commercial waggon and the adaptation of the internal-combustion motor to agricultural uses. In the steam-waggon section, during the past three years, such well-known makers as Thornycroft, Coulthard, Leyland, Foden, Clarkson and Capel, and others have scored success after success, not only in special premium test trials in this country, on the Continent, and in the United States, but in the still more searching and convincing test of road use, under all conditions, week in, week out. In the heavy oil internal-combustion-engined waggon, less, it is true, has been done; but that less scores as against practically nothing abroad, for the Hornsby-Akroyd motor-waggon, which recently won the War Office special £2,000 prize and bonus, not only travelled across several counties to do so, but found no competitors. In agricultural work Messrs. John Scott, of Edinburgh, and Dan Albone, of Briggleswade, have each adapted Simms motors to a tractor-cultivator and agricultural tractor respectively. These, in addition to doing all descriptions of field work and farmyard work at about half the cost, in something like a third of the time, with less than a third of the number of men and horses, and without any danger of fire, are faster on the road than a steam traction-engine by some 50 per cent.; thus facilitating the carriage to market of the produce they have cultivated or harvested with such astonishingly economical results. The Scott device is so contrived that it can be readily converted into a motor market waggon—capable of a 14-mile speed—by the removal of its agricultural mechanism, a matter of a few minutes' work. Its cultivators, too—which are capable of any work, deep or shallow, in any soil, and thoroughly pulverise and *aërate* the latter—thus save the cost of several implements. Withal, the cost of either Scott or Albone ("Ivel") machine, with a 20 b.h.p. motor, is little more than that of a plough and two pair-horse teams. Yet twice this number of horses are required to do the same work at twice the cost. From all these facts it appears that the agricultural branch of the British motor industry will be one of the most important, if only on account of its unrestricted scope and demand.

Such, then, stated as briefly as possible, latterly in mere outline, yet throughout with the view of giving due prominence and proportion to the influences, men, discoveries, and conditions generally that have made it, is the history of automobilism in Europe up to the present time. That the bulk of the progress made has been due to the lack of hide-bound restriction abroad, and to the enterprise and genius of continental engineers, cannot be denied. But if we admit this (as we must), how shall we express our appreciation of the enthusiasm, genius, and patient endeavour which have not only enabled British engineers to profit by every step of continental progress as it was made, and share its results, but eventually to surmount the effects of the restrictions under which they had so long laboured, and ultimately to lead in the one path where they formerly were compelled to follow? Surely theirs are the greener laurels, the more lasting honours.

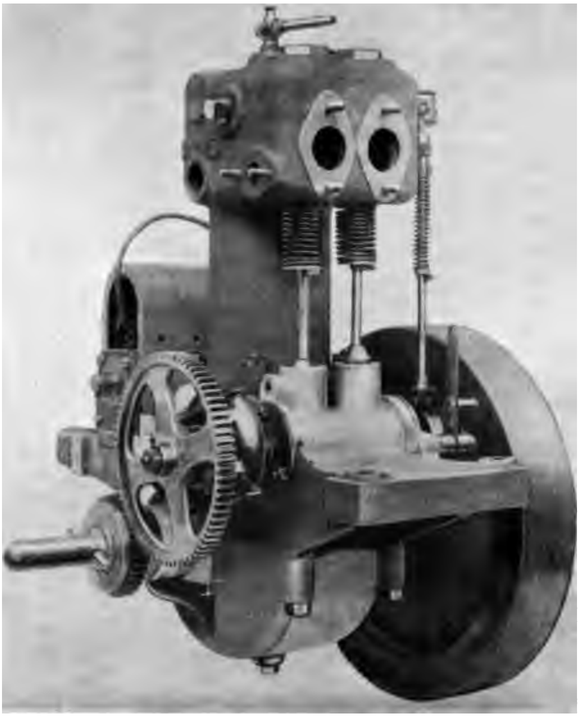


FIG. 1

A TYPICAL SINGLE-CYLINDER MOTOR, FOUR-STROKE TYPE

PART II

DESCRIPTIVE

CHAPTER III

INTERNAL-COMBUSTION MOTORS

AT the outset of any work dealing with the motor industry, the first question the non-technical reader will ask is, What is a motor?

Strictly speaking, a motor is anything—from a certain order of brain-cell to the engine of an ocean liner—which produces movement; either for itself, for something else to which it may be applied, or for both combined, as in the case of all forms of locomotion. And here it may be said that the importance of that phrase "for both combined," in so far as it relates to the weight of the whole, can hardly be over-estimated: a point which will become apparent early in the present work, and clearer throughout its progress in detail.

For the purposes of this work, nevertheless, the above definition may be narrowed down to those mechanical constructions producing motion which are and have been used for the auto-propulsion of road vehicles and the smaller classes of vessels; from bicycles, or launches a few feet in length, up to the largest waggons or craft of a couple of hundred tons or so. These motors belong to any of four distinct classes, namely, "internal-combustion" motors, steam engines, electric motors, and compound motors: the last-named being a combination of the first and third.

Chief among these is *the internal-combustion engine*, of which (in its four-stroke type) the following index of parts is appended:—

		FIGS.
1.	Compression-chamber	1
2.	Piston	1
3.	Induction valve	1
4.	Slots in air-inlet cap	1
5.	Vaporiser	1
6.	Jet	1
7.	Insulated pin	3 and 4
8.	Interrupter	1, 3, and 4
9.	Connecting-rod	1
10.	Crank	1
11.	Crank-shaft	1
12.	Exhaust valve	1
13.	Exhaust cam	1
14.	Exhaust silencer	1
15.	Lid of vaporiser	1
16.	Needle-valve guide	1
17.	Air-admission cap	1
18.	Magneto machine	1 and 3
19.	Magnets	1 and 3
20.	Oscillating envelope	3
21.	Armature	3
22.	External arm of magnet	3 and 4
23.	Magneto driving-crank	3 and 5
24.	Half-speed shaft	1 and 5
25.	Terminal	1 and 3
26.	Wire	1 and 3
27.	Ignition plug	3
28.	Crank-chamber	1
29.	Interrupter spring	3
30.	Trip-rod	1 and 3
31.	Ignition cam	3, 4, and 5
32.	Interrupter arm	3 and 4
33.	Key-piece	5
34.	Ignition shaft	5
35.	Timing-gear sleeve	5
36.	Timing-gear fork	5
37.	Timing-gear lever	5 and 1
38.	Lubrication groove	1
39.	Exhaust-rod guide	1
40.	Trip-rod guide	3
41.	Inlet valve, regulating lever	1
42.	Groove for timing-gear key-piece	5
43.	Nut on trip-rod	3
44.	Tappet	3 and 4
45.	Top nut of plug	3
46.	Bottom nut of plug	3
47.	Float-feed filter	1
48.	Compression tap	1
49.	Induction-valve head	1
50.	Exhaust-valve roller	1
51.	Float chamber	1
52.	Float	1
53.	Petrol tank	1
54.	Water-jacket	1
55.	Water-connection flange	1
56.	Water-connection flange	1
57.	Induction-valve spring	1
58.	Induction-valve cage	1
59.	Exhaust-valve spring	1
60.	Trip-rod spring	3 and 1
61.	Needle valve	1
62.	Overflow pipe	1
63.	Magneto machine connecting-rod	3
64.	Exhaust flange	1
65.	Tap for petrol tank	1
66.	Guide on plug	3
67.	Trip-rod cottar	1 and 3
68.	Trip-rod collar	1 and 3
69.	Exhaust-rod collar	1
70.	Exhaust-rod cottar	1

This, by the operation of the well-known physical laws of Boyle and Charles, generates its power within its own cylinder or cylinders—whence its generic name

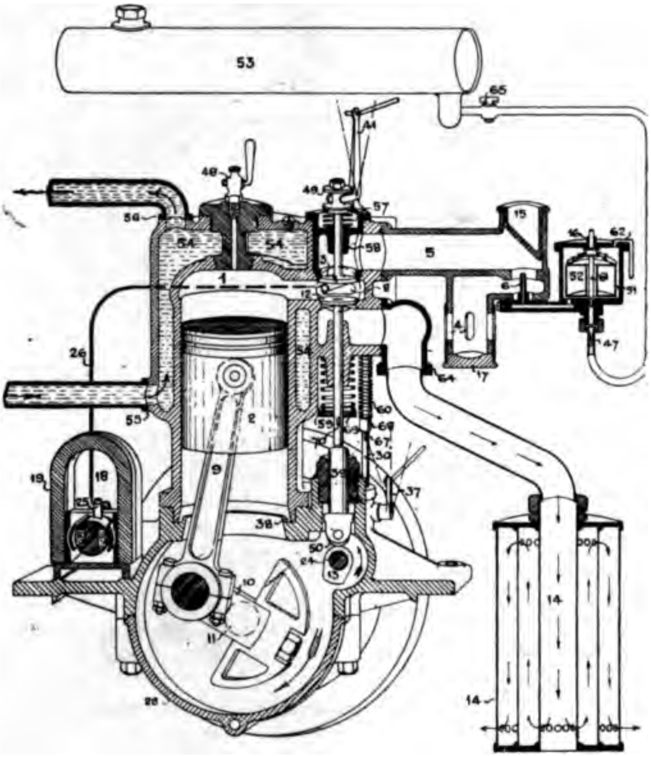


FIG. 2
DIAGRAMMATIC SECTION OF TYPICAL FOUR-STROKE MOTOR

—owing to the intensely rapid expansion of a carburetted charge of air, previously compressed to several atmospheres; which expansion again is due to the combustion of an induced inflammable charge of atomised or vaporised liquid hydro-carbon which has been intimately diffused throughout the air-charge. As all this occurs within a closed cylinder, energy is developed, which acts mechanically upon a freely moving, yet gas-tight piston, connected by a rod to a crank on a shaft. This shaft, mounted in suitable bearings of metal, which is slow to heat under friction, is also free to move, but in a rotary direction as to its own axis only. It carries a flywheel of more or less weight, the weight of which is required to store

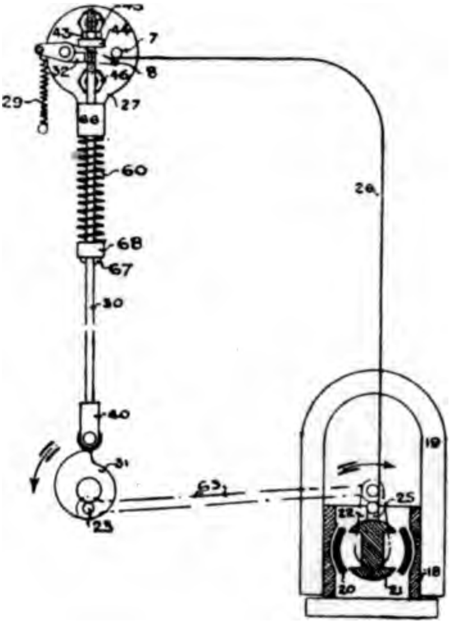


FIG. 3. THE SIMMS-BOSCH MAGNETO (THE MAKE)

the energy imparted to the reciprocating piston and rotating shaft by the combustion above mentioned. These parts, then, with a gas generator, cylinder-cooling, lubrication, and ignition systems, are the essentials of such a motor. The need for the first- and the two last-named needs little or no explanation; but it must be understood that a cylinder-cooling system is necessary because the combustion and expansion generate heat to about 2,000° C., or from 70 to 80% more heat-energy than can be turned into mechanical work. Consequently, without some cooling system, the cylinders would rapidly become so hot as to seize the piston and

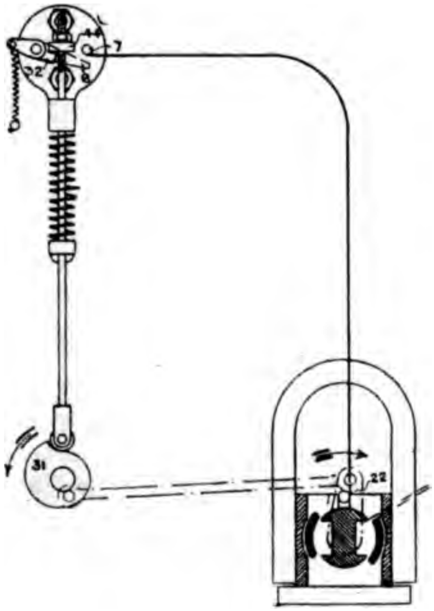


FIG. 4. THE BREAK

stop the motor, especially since the best lubricants burn at 300° C.

Actually these motors are *hot-air expansion engines*, although almost entirely different from those which are specifically known by that name. One cannot be too clear upon this point. All, however, depend for their working upon the above phenomena, the principles of which were discovered by a French engineer, Alphonse Beau de Rochas, who on January 7th, 1862, took out a French patent for a motor compressing the charge, and published a pamphlet about the same time, in which he laid down certain rules for the constitution and efficient working of such engines. These rules are now regarded, in principle at least, as constant laws, so far as four-stroke motors are concerned; that is to say, those in which the piston makes four strokes—in and out alternately—for every impulse it receives from a combustion, thus making *one* working stroke during every *two* revolutions of the crank-shaft. They also hold good, in respect of the necessity of compression before combustion, with two-stroke motors; that is, those in which every out stroke is a working stroke, a combustion occurring *once* during every shaft revolution. The order of the various piston strokes of an engine is called its *cycle*, which, as will be seen, does not correspond with the number of revolutions made by the crank-shaft each for each. Thus, in the Goret engine, three such revolutions go to the cycle; in the one under discussion two, and in the two-stroke motor one.

The immediate result of this, for one thing, is that the four-stroke motor has other essential parts beside those previously mentioned. These are first, valves, which open to admit the air and gaseous charge; or allow the burnt gases (the exhaust) to escape after combustion; springs to keep the valves closed—or in one instance, at least, the Weller engine—to hold them open; rods to push the valves open at given periods in the cycle; a cam-shaft, with cams moving the rods up and down; and gears (cog-wheels) on cam and crank shaft to rotate the former. And now that hot-tube ignition has been superseded by electric ignition, a commutator is essential to motors of more than one cylinder, in order to commute or distribute the current to each cylinder *once* during its cycle. This commutator will be described later on; in the meantime suffice it to say that it is a device in which the outer portion is stationary and mounted on the motor or car, the inner part being rotated by gearing or otherwise from the crank-shaft.

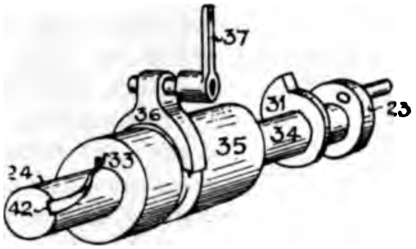


FIG. 5. CAM-SHAFT AND MOUNTINGS

The valves are of the poppet or mushroom type; that is to say, discs, the edges or underfaces of which are machined and ground to an even surface, so as to make a gas-tight fit in or upon the entrances to the cylinder which they control. Each of these discs is mounted upon a central spindle or stem—like a daisy and its stem—upon which again a strong spring is mounted. Inlet valves are of two kinds: automatic—those which are opened by the atmospherical suction of the piston during its out stroke to draw in the new charge—upon which the spring is weaker; and those which (like the exhaust valves in all cases up to the present) are mechanically operated, either by the action of the rods above mentioned, or by one end of a short pivoted lever—a tappet—placed at right angles to the valve-stem, the other end of which is lifted or dropped by the rods. These rods are in all cases held in line with the valve-stems, and at right angles to the cam-shaft, which, as has been said, moves them up or down with its cams. Thus in engines with mechanically operated (m.o.) inlet valves there are two such rods for each cylinder; in those with automatic (*i.e.* atmospherically opened—a.o.) inlets, only one; namely, that which moves the exhaust valve-stem or rocking lever, as the case may be.

Each rod is lifted or dropped by a cam; that is, a piece of metal (originally a disc out of which segments of various size and shape have been cut) mounted eccentrically upon a cam-shaft. And, beside carrying a strong spring to keep it down on the small roller on its lower end, ready for immediate contact with its cam, the rod is held in a guide, so that it cannot get out of line with the cam and valve-stem, and generally so that it cannot rotate. Each cam is formed or keyed, or otherwise mounted upon the cam-shaft at 90° from its fellow—either inlet or exhaust—so as to form, as it were, a projection next to it. As the shaft rotates, each cam lifts or drops its rod, one rod lifting after the other falls. The cam-shaft is mounted parallel with

the crank-shaft, in bearings, usually inside the crank-case. This is a box-like structure on which the cylinder is mounted, cast usually in halves, vertically or horizontally, and contains at each end the end-bearings of the crank-shaft; and usually intermediate bearings between each crank. Now, in order that the cam-shaft may be rotated at a fixed rate with the latter, it has the larger of two spur-gears or cogged wheels keyed on one end. This gear has twice as many teeth as its fellow, which is similarly mounted on the crank-shaft, the teeth of one being in perpetual engagement or "mesh" with the teeth of the other. The chief effect of this arrangement—another will presently appear—is that the cam-shaft only rotates *once* during the cycle; that is, once during every *two* crank-shaft rotations.

In some motors, of two or more cylinders, the inlet and exhaust valves are in projecting opposite sides of the cylinder head. These projections, which contain the valves and their seatings, are known as valve-chests. Consequently two cam-shafts are fitted, one at each side of the crank-chamber, each with its larger gear meshing in common with the smaller gear on the crank-shaft. The effect is the same, of course, so far as their rotation-rate relatively with the latter is concerned; but each cam is set at 90° with the one *opposite* it, on the other shaft. The commutator, too, is geared in a similar "two-to-one" fashion with the crank-shaft. This construction, though simple-looking, apparently free from complications, and so forth, and therefore adopted by many leading makers, in my opinion, is not so good as it looks. In the first place, it adds the weight of an extra shaft and gear; and in the second, it creates an extra part which may go wrong—

—though I admit it rarely does so—as the key of the gear, or the screw which secures it to the shaft, may slip, and put the whole cycle wrong. A good general rule, both in practice and engine-selection, is, "the more parts, the more complication" or liability to go wrong, and obviously the more weight. Nevertheless, this need not (and should not) clash with another good rule, "one part, one function"; although, again, contradictory as it may seem, the more functions one part can be made to undertake *efficiently*, the better. Thus we find that in other motors, and those among the latest, one cam-shaft actuates both inlet and exhaust valves, as well as the spindles which operate the make-and-break—*i.e.* the spark-producing mechanism—of a rupture-spark electric-ignition system.

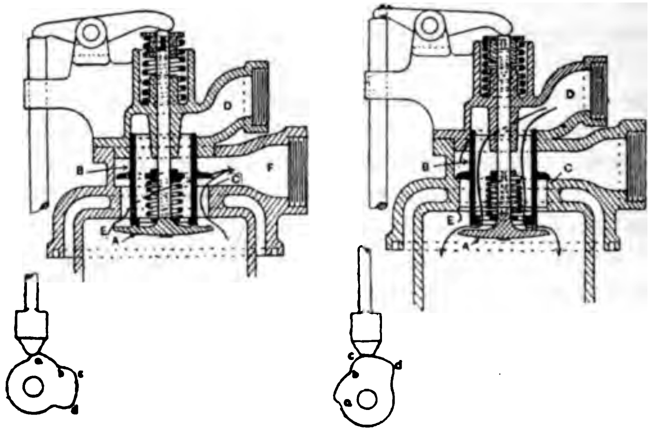
Now that the various parts of the four-stroke motor and their function have been described, we shall be the better enabled to understand the Beau de Rochas cycle. This consists:

Firstly, of an outward *suction* stroke of the piston, which acts as a pump as the inlet valve opens, to draw in the inflammable gaseous charge from the gas-generator or carburettor. In motors with m.o. valves, the cam-shaft (rotating with the crank-shaft, which again is rotated by hand at starting) lifts the valve. When the piston has drawn the full air-and-gas charge into the cylinder, and reached the end of its stroke, the valve closes—or is dropped by its cam—and:

Secondly, the piston rises for an inward or *compression* stroke, in which the charges are intimately mixed—though some say *not* combined—and compressed ready for firing as soon as the piston has reached the top of its stroke. The cams, though turning, are "dead," *i.e.* not moving their rods; with the exception of the ignition cam of a cylinder with the rupture-spark low-tension system. This cam, as soon as the piston reaches the top of its stroke—or nearly so—and the crank-shaft completes its *first* revolution, drops its rod, the spark is made, and:

Thirdly, ignition and combustion of the now fully compressed charge occurs, and the outward *working* stroke begins; throughout which—though at a rapidly falling rate—the enormous expansion consequent upon the combustion (to a heat of some 2,000° C.) violently develops energy upon the piston, the strength of the energy diminishing towards the end of the stroke by some 40 %. During this period of the cycle *all* cams are inoperative; until:

Fourthly, the *exhausting* inward stroke begins; the exhaust cam lifting its rod to open the exhaust valve smartly, for the inward sweep of the piston to "scavenge" or discharge the exhaust or burnt gases, and the products of combustion (if any) through the valve into the exhaust pipe. Here, again, much of the energy developed is necessarily lost; and in some engines, in which the carburation is bad, or the spark too small, or not hot enough to produce complete combustion of the charge during the fraction of time in which the working stroke occurs—in four-stroke engines from 2·8 to ·06 sec.—I maintain that anything from 15% to 35% of the charge passes out unburnt as "green gas." The cycle is now complete, and the crank-shaft has made its second turn; the above four operations being repeated in the same order indefinitely. Such, then, is the Beau de Rochas or four-stroke cycle; and it will be seen that if the gear had slipped a cog, or halted, from any cause, the cycle would merely have been *uniformly* interrupted in a motor with a single cam-shaft: whereas with two shafts, the other one rotating *normally*, it would have been absolutely upset. And the cycle being now understood, mention may be made of two of the latest French motors, the Selbach and the Bailleul, in which the construction is such that *one* valve only per cylinder is used, acting *alternately* as inlet and exhaust valve, being actuated by a rocking lever, rod, and a special cam geared so as to rotate at half-turns with the crank-shaft as in other types. This is such a radical departure from general practice—although the idea is not altogether new—as to require detailed explanation of two facts, the first being that owing to the terrific



SECTION OF SELBACH SINGLE-VALVE ENGINE
FIG. 6. EXHAUST VALVE OPEN FIG. 7. INLET VALVE OPEN

A, mushroom-headed valve with two seats; B, sleeve surrounding A carrying a flange; C, seat upon which the flange of B rests; D, intake from carburetter; E, valve seat for A; F, exhaust port

heat to which exhaust valves are subjected, they burn and scale. This scaling or "pitting" leaves them no longer gas-tight, and they have to be re-ground or renewed. The second point is that the rapidly induced gaseous charge, being composed of a liquid hydrocarbon (petroleum spirit, alcohol, paraffin, or benzol) atomised with air, actually constitutes a freezing mixture, so much so that special provision is frequently made to pass hot exhaust gases round the carburettor, to prevent the mixture being contracted to such a small volume that more liquid fuel is drawn in than is required, and to prevent the latter being recondensed.

Consequently, the idea of this single-valve construction is that this mixture shall keep the valve cool after each exhaust, while the exhaust heat of the valve reacts on the mixture to bring it up to a suitable temperature as it enters the cylinder. And so long as a screen of wire gauze—on the principle of the Davy lamp—be placed in the joint of the inlet pipe, it is difficult to see how a back-fire—even from an incomplete previous exhaust—can get into the latter, especially as the stem of the valve itself is surrounded by a small movable cylinder or sleeve, which is so formed as to act as a continuation of the inlet passage during the charging stroke, and as a shield for it during the exhaust. This, by the way, is more than can be said for any a.o. valve of the ordinary type, as its spring, upon which efficiency solely depends, rapidly loses resiliency in use, if not by the heat of the cylinder head.

In these motors, however, the valve opens as shown downwards in the cylinder head, the inlet pipe opening directly round the guide and spindle; the spring on which is above, outside the head, while the movable sleeve above mentioned is sprung on the valve-spindle, and rises or falls with the valve. Round its outer wall this sleeve has an annular flange, which engages with the floor of the exhaust passage (situated below the inlet)—the result being that its travel up and down is limited. Now the cam, which is cut so as to form exhaust and inlet cam in one, opens the valve *further* at the charging stroke than at the exhaust—or in the reverse manner in the Bailleul—so that during the former the valve leaves the sleeve as soon as the flange has engaged with the floor of the exhaust passage, the flange thus preventing any of the new charge flying upwards into the exhaust. During the exhaust stroke, on the other hand, the sleeve remains seated on the valve, its flange thus rising from the floor of the exhaust passage and leaving the exhaust gases ample room to escape. Consequently, though these gases pass round the sleeve, they cannot enter it, as its spring keeps it firmly seated on the valve.

The same idea of cooling governs the construction of the older D'Ecquivilly valve, which consists of a smaller inlet valve (a.o.) contained in the hollow stem of a larger (m.o.) exhaust valve, the head of the latter forming the seating for the former. The same advantages are claimed, but these would appear to be offset by the fact that there are two valves—and one of them a.o.—instead of one, to grind to a gas-tight seating. Again, if an a.o. valve sticks—as it often does—the cycle of the motor is upset. This cannot occur with a mechanically operated valve. Some inlet valves, too, are made especially large, so as to enclose two, three, or four smaller a.o. valves; though one would imagine that the extra size alone would secure all the advantage, if any, to be gained, without the complication of additional working parts.

We may now discuss the cooling, lubrication, and ignition systems. All internal-combustion motors are either air-cooled by radiating metal flanges on the head and upper half of the cylinder—the extra metallic surface cooling the motor *so long as it is exposed to a strong current of air by the travel of its vehicle*—or water-cooled by means of an outer cylinder containing water, which forms an annular chamber around the working cylinder and its head. This is the water-jacket, the water in which is kept cool by being pumped rapidly to and from the jacket through a series of pipes fitted with radiating flanges. Latterly, a zinc tank made like a honeycomb has been used instead of radiator pipes; and, still more recently, a series of some two hundred light vertical zinc tubes, expanded into two shallow tanks, upper and lower, has been introduced, and is said to have proved more efficient than the costly, leaky honeycomb. All these tubes, furthermore, run through a series of about twenty thin sheets of zinc of the same breadth as the tanks, all the sheets being brazed about half an inch apart. Thus both tubular and cellular radiation is obtained. Latest of all is a frame-shaped tank; the space within which contains a continuous pipe, running, as it were, in horizontal layers from top to bottom of the frame; each layer of piping carrying about a hundred vertical flanges or gills of sheet copper, which practically form a series of cells. Neither of these two last are subject to leakage, and all three are cooled by a rotary fan driven by a belt off the front of the motor.

Circulation, as has been said, is effected by a small pump—piston or rotary—attached in any convenient situation on the crank-chamber, usually at one side near the front end, and driven by a small gear meshing with the cam-shaft gear in a ratio of about three to one. Small motors up to 10 h.p. or so—especially of the horizontal type—are frequently cooled without a pump by what is known as the thermo-syphon, or "natural" cooling system. In this the tank and radiators are placed with their lower parts on a level with the head of the motor, so that the water connections lead from the top of the jacket to the top of the tank and into the bottom of the former from the lowest row of radiator pipes. The tendency of heated water is to rise, and that of cold water to seek a not over heated surface if free to do so. Consequently, as the water heats in the jacket, it rises to enter the top of the tank, drawing in the colder water to take its place. It is probable, however, that the latter enters to a great extent by gravity. The result is that a continuous and automatic circulation is maintained. The system is a good one, because cooling is not too rapid; which tends to economy of the heat-units developed, and therefore to conservation of power. Also the danger of cracking a cylinder through a sudden flushing of cold water is eliminated. Yet it is said to be too slow in warm weather: and it is not easy to calculate the amount of radiation required in the larger motors. Air-cooled motors are chiefly used for motor-cycles and the lighter cars, and latterly many of the former have been fitted with syphon-cooled, water-jacketed motors. Marine motors need no radiators, the water circulation being effected by pumping the water from outside the hull and back again.

Lubrication is effected in a score of ways; but all variations come under the three main headings of forced-feed, gravity-feed, and splash lubrication. The second and third, as the most restricted in a sense, may be discussed first and dismissed. Pure gravity-feed is practically only used on small marine motors—on large ones it is rapidly being superseded—its apparatus consisting of an oil-cup of brass, or more frequently a "sight-feed" cup of toughened glass, with a metal cap in which is a little shuttered air-hole, the closing of which regulates the supply through the tube beneath the cup to the part to be lubricated. This is the simplest form of gravity-feed, and is generally applied, where used at all, to external parts; although sometimes used, as said, in small marine motors for cylinder (or rather piston) lubrication. In some examples, however, a horizontal metal cylinder, with glass ends for "sight-feed" is fitted. This supplies oil to all parts through a series of copper tubes. Sometimes, as in the Holt lubricator, a suction diaphragm opens a valve and permits the oil to flow, the suction being effected by connection with the charge-induction pipe on the motor. These lubricators have the two great defects of not stopping when the motor stops, the oil thus running to waste; and of being subject to "air lock," *i.e.* a vacuum formed between two doses of oil when the air-supply has been improperly regulated.

Splash lubrication is practically universal for all bearings inside the motor, such as those for the crank-shaft, cam-shaft, and cams, enclosed gears, and the lower ends of the connecting-rods; and, sometimes, when a tongue or dasher is attached to the last named, for the cylinders. It simply consists of a bath of oil inside the crank-chamber, the cranks dashing the oil over all working parts. It is a dirty, but thoroughly effective system ; and is also used for the differential gear and the change-speed gearing, the nature and construction of which will be discussed later.

Forced-feed lubricators are of two kinds, mechanical and physical ; of which it may be said that the former are those in which the oil is driven by mechanical means to various parts. Most of them are complicated of necessity, seeing that the feed, though powerful, must be limited in quantity. Consequently they waste power. And although this waste is admittedly slight, it is not good engineering practice if it can be avoided. This is done by physical force-feed lubricators, which, on the other hand, waste neither power nor oil ; as they stop working when the motor stops, in the first place, and, secondly, drive the oil to the points required by the action of exhaust steam, or gases, or by the pressure of the water circulation. In a typical example of the first, one steam inlet creates a suction above the sight-feed, drawing the oil up drop by drop, while another, entering the oil container just below, forces it up, each inlet being hand regulated. In the Dubrulle lubricator, the best-known example of exhaust-gas forced-feed, the delivery tubes pass up through, but do not open into, the oil box, entering glass sight-feed tubes at the top. These last are interconnected by a horizontal bridge tube, connecting with a vertical tube from the oil box, into which the exhaust gases from the motor are led, the pressure of the exhaust driving the oil up into the sight-feeds and down again through the supply tubes. The third type is the simplest of all, and is used on some of the latest Simms and the F.I.A.T. (Fabrico

Italiano di Automobili, Torino) motors. In this a pipe leads to the bottom of the oil container from the water-circulating system, and the oil consequently floats upon the water and is forced up through the sight-feeds to the supply pipes. There is a gauge-glass in the oil box to show the relative level of the oil and water, the supply of the latter being cut off by a cock on the water supply pipe as soon as the former is expended.

The best lubrication practice, in my opinion, so far as the direct supply of oil to all working parts is concerned, is the centrifugal method adopted by Maudslay in England, De Dion-Bouton, and one or two others. Forced-feed, it is true, is mechanical, but as this is effected by a pump on the engine itself, it is free from complications. It is equally applicable, however, to any of the above physical systems, consisting as it does of a series of channels—called "leads"—bored centrally through the crank-shaft, cranks, crank-pins, connecting-rods, and gudgeon-pins (in the pistons). The oil is thus driven by centrifugal force through all these to their bearings and upwards through the connecting-rods and gudgeon-pins to the walls of the cylinders, which last are also lubricated direct from the apparatus. As will be seen, this system is thorough, clean, and economical.

We may now consider the various ignition systems used in internal-combustion motors. These are six in all, namely, tube-and-continuous-lamp, bougie-and-temporary-lamp, hot-chamber-and-temporary-lamp, adiabatic, catalytic, and electric, with high or low tension. The last, beside being the one in most general use, is, singularly enough, older than any of the others. It is even older than the modern internal-combustion motor of the compression type, either two- or four-stroke; one form of it having been described by R. L. Bolton in 1853, and others by Barsanti and Matteucci (1854–1861), Lenoir, with spark plug (1860), Otto (1863), A. D. Cherfils (1865), and R. George (1866). None of these, however, are now used, present-day types being mostly variations of Tenting's, Mors', or De Dion's systems. As to the first-named system—tube ignition—it was invented by Gottlieb Daimler in 1885 for igniting the charge in his motor, which was the best embodiment at that date of Beau de Rochas' principles, and was unquestionably the first of the modern light internal-combustion engines suitable for road-locomotion. His method was to screw a tube of platinum, with its outer end closed, into the combustion-chamber, the free end being kept hot by a continuous lamp-flame, so that when sufficiently compressed—probably at a low pressure—that portion of the charge in the tube was fired by contact with its heated surface.

This system, however, is open to numerous objections—although makers have clung to it as a supernumerary until within the last couple of years or so—for though the platinum tube wore fairly well, despite the heat, even an alloy of the metal was worth its weight in gold, and it was liable to contract unequally when cooled, and cause failure of compression. Its worst faults, however, were that the ignition-moment could not be varied, and that the lamp-flame, even though protected by a shield, constituted a perpetual source of danger, especially with the engine running and the car at rest, when the petrol vapour hung about the car instead of being dispersed. Furthermore, the lamp was always liable to be extinguished. Other metals, such as silver, copper, and nickel, as well as porcelain, have been used for tubes, but have not proved satisfactory, as they equally possess all the above faults, as well as molecular weakness.

The inconveniences of continuous lamp-flame have been eliminated since Daimler's time, by using bougies or solid rods of the above metals—generally copper, as it is the best heat conductor—which, after preliminary lamp-heating, are kept incandescent by the heat developed in the cylinder head, so that the lamp is not required further. This bougie-ignition is used on various stationary oil engines and marine motors, and is fairly satisfactory, because the load is nearly constant, and the variations of engine-control from moment to moment are not wide, being effected either by interrupting the fuel-feed during the fraction of a second, or likewise delaying or maintaining the opening of the exhaust valve. Now, with a constant load, checking the fuel-feed and keeping the exhaust valve open late is a good economical system, but *as a means of timing the ignition* would probably cause loss of power in a car engine. Timing by opening the exhaust valve late—as practised in tube-ignited motors hitherto—unless the greatest skill is used, entails extravagant use of fuel, premature ignition, and, worst of all, overheating.

But this last-named defect has been turned to practical account in the system of hot-chamber or bulb ignition, in which the combustion-chamber is extended into an external bulb, dome, or closed cylinder, into which the fuel—paraffin, petrol, or alcohol—is injected under pressure through a needle-hole, while the motor-cylinder aspires nothing but air, the bulb being heated by a lamp at starting. This system is perhaps the most economical in fuel of any; and as the fuel-pump is driven by the motor, it follows that by governing its stroke the ignition can be timed to a nicety. With stationary and marine (constant-load) motors it is nearly ideal, its only defect being that the fuel-delivery tubes are extremely narrow, and so may choke or be torn off; or the pump may fail, in which case the motor is put out of action. It might answer for automobile work, with petrol or alcohol, but would probably cause the motor to foul with tarry soot if paraffin were used, on account of the perpetual variation of the load.

Adiabatic ignition, anticipated by Beau de Rochas, is that in which, by compression to about twenty atmospheres, some 300 lbs., the gaseous charge is made to ignite spontaneously. This system, however, entails the use of separate pressure cylinders, and is consequently too cumbrous for any but industrial purposes. We may therefore pass to the next on the list, catalytic ignition, the ideal system in theory and the only automatic one (although some alleged catalytic igniters require heating with an electric current to make them incandescent at the start), as it depends merely upon the property possessed by certain of the rarer metals, such as spongy platinum and osmium, of glowing when plunged into a gaseous mixture. In practice, however, it has hitherto been found difficult to achieve this, not only on account of the cost of these metals, but because of their fragility. It may be, however, that a tube of ordinary platinum, so fitted that a portion of the mixture might be blown rapidly through it, would become sufficiently incandescent to ignite the charge, on the well-known principle of the Paquelin thermo-cautery. Gans de Fabrice considers that, as the temperature of such a device would be nearly double that of an electric spark, it would increase the efficiency of the motor some 40 per cent. or more. As the heat of the ignition medium is known to increase motor-efficiency, he is correct, provided that his conditions are as stated. Probably, however, the expansion shocks would speedily destroy any device made of spongy platinum unless arranged as a plunger; which, as it can be mechanically operated and timed from outside, would appear to be the arrangement most likely to be adopted in the future, as the last step perhaps in perfecting the internal-combustion motor.

Electric ignition is effected, both on the high- and low-tension systems, by the interruption of the circuit of an electric current, either between two points fixed about $\frac{1}{40}$ inch apart—the jump spark—or by the mechanical moving apart—the rupture spark—of two points previously in contact; one point, of course, being fixed and the other movable. The essentials for each naturally vary in number as well as in the methods of applying them, but are here given only from the functional point of view, some being common to both systems. In the high-tension system we have first a spark plug, that is, a threaded cylindrical plug of metal containing a hollow column of porcelain, mica, steatite (soapstone), or other insulating material capable of standing the heat developed in the cylinder head where the plug is screwed in. This column contains a platinum, nickel, or steel wire; usually the first, and in any case with a platinum point which hangs centrally in the inner end or mouth of the plug; and either curves towards one side of it, or is met by a short hook or bridge (of platinum or the same metal of which the plug is composed), the gap between their two points being $\frac{1}{40}$ inch apart. The second essential (in both systems) is either a small magneto or dynamo, or a primary or secondary battery (for the construction and nature of which see the chapter on electric motors), or both combined. This is the source of the current.

The third is a high-tension coil, that is, a coil with two separate windings of insulated wire, the inner of which (the primary winding) is the thicker and shorter. This is wound round a bundle of soft iron wires or plates—the core. One of its ends is usually secured through a stud to an arm connected up with a contact breaker in connection with the positive pole of the battery, while the other is connected with the negative pole. This arm is fitted with a set screw, situated immediately above the free tip of a leaf-spring—the trembler—the other end of which is held on a stud or terminal in contact with one end of the secondary winding. This wiring is longer and thinner, and though mostly wound to about the same depth as the other, which it surrounds, has more turns. Its other end is also secured to a terminal, from which it is "earthed" by an outside wire to the metallic mass of the motor. Similarly, its first-mentioned end is connected from its terminal to the spark-plug. It thus forms a secondary circuit of its own, in connection with the primary circuit, through the trembler, and a device consisting of insulated sheets of tinfoil, known as the condenser. This is connected at one terminal to the primary, and at the other terminal to the corresponding end of the secondary winding by wiring of *primary thickness*, linking the two circuits, as it were, "across" the coil. Now the secondary winding being the thinner, opposes more resistance to the current, which, aided by the resistance of the condenser, compels the induced current to travel along it at *higher pressure or tension*, if the same amount is to pass in the same time. Hence the name. But obviously, the insulation must be perfect throughout, as any break would cause the current to complete the circuit through earth instead of through the plug to earth. This constitutes one of the very few defects of electric ignition, which would otherwise be ideal.

CHAPTER IV

INTERNAL-COMBUSTION MOTORS

(*Continued*)

HAVING concluded the previous chapter with a description of the parts employed in high-tension electric ignition, we may now consider their function. We find, first of all, that when an electric current is led into the primary winding of a coil, it converts the wires or plates of the core into a series of magnets. These attract a small piece of soft iron on the under side of the free end of the trembler, and pull it away from the set-screw in connection with the end of the primary winding. This at once breaks the primary circuit of the current, upon which the core immediately ceases to be a magnet, and so leaves the trembler free to make another contact with the set-screw of the primary. On the instant of new contact, however, the current circuit is again completed and the core immediately *re*magnetised, only to be again *de*-magnetised as before. This operation, which takes place many times in the course of a second—according to the screw adjustment suited to the speed of the motor—is the spark "make-and-break," the current make-and-break from the battery being effected by the contact-breaker previously mentioned. This latter, being actuated by a cam on the half-time shaft (keyed

so as to make contact at or near the moment of highest compression) completes the primary circuit by bringing the battery into contact with the primary winding of the coil *once* during the cycle.

Meanwhile, the trembler, in contact with the secondary high-tension winding at its other end, has acted, together with the condenser, to conduct the current from the primary circuit at the moment of contact with the set-screw—*i.e.* at the " make "—the double bridge thus formed being broken again at each " break." The current thus induced through the condenser and trembler into the thinner secondary, on account of the resistance set up, becomes a high-tension current. It then immediately flashes along the secondary; thence through its high-tension wiring to the spark-plug conducting wire; leaps the gap, as a spark, to the platinum tip of the plug-cylinder in metallic contact with the " earth " mass of the motor; and thence passes back to its starting-point. As this circuit is made, as has been said, many times in a second, the resultant stream of sparks at the gap fires the charge. The frequency of the sparks is due to the high resistance the current has met, and corresponds to the resistance of the condenser, and to the number of turns in the secondary winding, as well as to the strength of the current. Thus the power of the spark, and consequently that of each combustion, varies to correspond with this frequency.

Now, in order that the spark may be produced at the right moment, the mechanism of the contact breaker (between primary circuit and battery) is arranged so as to operate it early or late round about the period of highest compression. This is known as the advance and retard. The whole operation may be diagrammatically described as that of a double figure 8 thus; in which B is the battery, C the contact breaker, P the primary circuit, T the trembler, X the condenser, S the secondary circuit, and M its connections with the mass and spark-plug of the motor; TPX thus forming the primary circuit, connecting with the secondary by TX, and SMS the secondary circuit. However, in motors of two or more cylinders, the functions of the contact breaker C are assumed by a distributing commutator. This, in some magneto devices is keyed on a special shaft, which is geared off the half-time cam-shaft. In others it is keyed upon, or geared synchronously with, the latter. It is placed between the secondary winding of the coil and its spark-plug wirings, and has projections upon it corresponding to the number of cylinders; or has the same number of metal contacts sunk in its vulcanite disc; or else carries a like number of spark-plugs, making successive contact with a plug on the positive lead of the secondary wire; or in several other ways gives the same result, *i.e.* leads the current to each cylinder in its turn.

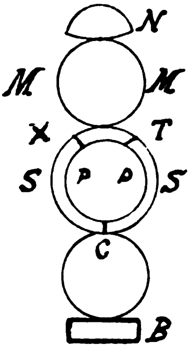


FIG. 8

Generally, with or without the magneto, the wiring to all the cylinders is led from a single coil; but in one or two systems there is a coil for each. The arrangement of the wiring, the number of terminals, and the grouping of the whole varies; but the above may be taken as a correct outline of the scheme of high-tension electric ignition. Lastly, a third or stationary contact breaker in the shape of a switch is introduced, generally in the primary circuit wiring, where batteries are used to prevent waste of power when the motor is not running. With the high-tension magneto or dynamo, in which the battery is only used at the start, this is a two-point switch. That is, one which, while maintaining permanent contact after setting with the primary circuit, breaks contact with (" cuts out ") the battery, and makes contact with the dynamo or magneto, so soon as the motor is driving the latter fast enough to give the required current for a large spark.

These devices—of which little can be said here in regard to their nature and construction that has not been fully detailed in the ensuing chapter on electric motors, to which the reader is referred—are now being universally adopted alike for high- and low-tension ignition, jump- or rupture-spark ; because they not only save current, as explained above, but give a larger and hotter spark than either primary or secondary batteries. This means that they not only give more power and complete combustion of large charges in high-powered motors, but materially increase that of the smallest. Still, since most of them are set to give a certain amount of current and size of spark at high, normal, and reduced speeds, it follows, as they are motor driven entirely, that they will not give sufficient current for the spark at very low speeds, still less at starting. Consequently they are not independent of the battery as a rule, and most of the few which are so require a spark coil, and a large one. As a fact, there are only three devices (that I can discover) in existence which are independent of both battery and coil, because their mechanical construction enables them to snatch the armature round, so to speak, at sufficient speed to give the normal spark, no matter how slowly the motor shaft is turning. These are the Houpied, Goodson, and Simms-Bosch magnetos, the last-named being the best, in my opinion, from every point of view. This difference, however, should be noted between electric motors and magnetos—which are otherwise much the same in constitution—namely, that the field-poles of the latter are *permanent magnets*, and so do not require excitation by accumulator current.

There is little, also, to say concerning the rupture-spark method of ignition, as any of the above systems of current induction are equally applicable to it. The construction of the actual sparking mechanism is somewhat different, however: the plug or stationary contact-point consisting of a steel rod, tipped with platinum, and thickly insulated from its threaded socket, beyond which it projects into the combustion-chamber. Its other end forms a terminal, to which the positive high-tension wire from the secondary winding is secured. The other contact point consists of the rocking-plate or arm, which is also tipped with platinum; and mounted as a gas-tight fit in a large plug, bolted valve-seating-fashion into the combustion-chamber, in such a situation—usually at right angles to the fixed contact—that the tips of the two contact pieces may touch each other. This ignition plug, however, is not insulated, and so constitutes part of the motor-mass to which the negative high-tension wire of the secondary winding is earthed.[1]

Outside the plug is mounted the mechanism—or at least part of it; usually a rapid cam, and in all cases a strong spring holding the rocking arm out of contact

[1] The high-tension system is rarely used with the rupture-spark, even in U.S.

with the insulated plug. By this spring the former is sharply snatched out of contact with the latter when the cam (mounted on the half-time shaft and actuating a rocking-arm spindle as a rule) arrives at the dropping point in its revolution. Whenever this sharp contact-break occurs, a large ("fat") and extremely hot spark —the rupture (hammer-break or wipe) spark is made, which leaps across between the suddenly disrupted points to fire the charge. There is at least a score of variations in the actuating mechanism—indeed, a simple platinum-tipped plunger-rod may replace the rocking-arm—into the respective details of which there is no need to enter. Suffice it, therefore, to say that the only essentials of the plug mechanism are the cam and the spring on the rocking-arm or plunger, which produce the sudden rupture of contact. Within limits, the longer the gap thus created, the better.

This is apparent, because the typical rupture-spark, being greater than the jump-spark, naturally increases the rapidity, and consequently the power of each combustion. For these reasons it is gradually being adopted as the standard ignition system, especially in combination with the more economical magneto or dynamo, which also increases heat of spark. Coming now to the low-tension system, we find that the essential differences are that the voltage is lower (because the coil only carries a primary winding), that it has no trembler, and only two terminals. The negative one of these is connected—per contact-breaking commutator, or direct in the case of the rupture-spark—to the positive pole of the battery, magneto or dynamo, while its positive terminal is attached to the insulated plug, in each case by a wire of the same thickness as the primary winding, a switch being also introduced between coil and plug. The negative terminal of the battery or its equivalent is earthed to the motor-mass to complete the circuit. The low-tension coil may therefore be regarded merely as a current intensifier, which is not needed when—as in the three magnetos previously mentioned—the voltage of the self-induced current in the armature is sufficiently great, owing to the higher velocity mechanically given to the armature revolutions, to produce a spark of equal size and intensity.

It has been argued that the low-tension system wastes the current. This is true enough when the battery is used, but is not so in the case of the magneto or dynamo, the current in which is self-induced, especially when the contact is so arranged as not to take place until the last instant before the cam-drop, sufficient contact only being given to make the circuit thoroughly complete. Furthermore, when the ignition-plug mechanism is of the "wipe-contact" type (that is, arranged so that the rocking-piece describes a circular path—hastened, of course, at the cam-drop—past the insulated plug, the tip of the former making a rubbing or wiping contact with that of the latter as it passes), both tips are wiped clean of any combustion products that may have been deposited on either through bad carburation or over-lubrication. These carbon deposits would otherwise insulate the tips, and "short"-circuit the current, otherwise prevent it completing circuit. This is the chief reason why the rupture-spark of the wipe-contact type is now being generally adopted both in the high- and the low-tension systems, and has quite displaced the jump-spark, in which the only remedy for a "short," in a sooty or cracked plug was a device known as the "intensifying gap."

This contrivance, which has quite lost its vogue during the past twelve months, needs some explanation. Its principle was discovered during the testing of a multiple-cylindered engine at the Panhard works. A new capped plug, in which a small spiral wire completed the connection between the wiring and the plug-conducting wire, was being tried also. On one plug this spiral was missing, yet that cylinder was firing better than the others. Search being made for the cause, the loss was discovered. Further experiments showed that the plug continued to spark as well as ever, though its points were purposely covered with soot and oil. Hence it was decided to create an artificial or secondary gap of $\frac{1}{20}$ inch or so outside the plug at any convenient point in the positive high-tension wiring. Now when an ordinary jump-spark plug becomes sooted, the soot forms a slight insulation, which, combined with the gap between the points, makes the effort required for the current to jump the gap and complete circuit too great for its normal voltage to overcome. Also a crack in the plug insulation causes the current, which is always seeking to complete its circuit at the negative of the secondary, to leak through the earth-mass by an outside instead of an inside path. Such a crack usually fills with soot during the next combustion after the crack has occurred, the charge being only half ignited, and that by the cylinder heat. But although such soot has an insulating effect, it provides an easier path for the current than the gap between the sparking points affords. And since electric currents always seek the path of least resistance, it still runs through earth outside the combustion-chamber and ignition still fails.

Yet if, on the other hand, a gap, carefully insulated so that it cannot leak to earth, be introduced at some point in the positive wiring of the secondary, the current pressure will be still further intensified in its effort to leap the gap. And its voltage being thus increased, it seeks an increased outlet or path through earth to the negative, which it finds at the gap between the spark-points. Such is the effect, at any rate, although its exact course after passing the intensifying gap is somewhat obscure, some authorities considering that a kind of loop current is formed. But the point is that additional current pressure is set up in the positive wiring on the coil side of the gap as well as throughout the secondary winding of the coil—more, indeed, than that winding has been calculated to stand—much as if an attempt were made to press a volume of water through too small a pipe. Consequently, friction and heating are set up, and the latter attacking the insulation of the winding, and gradually permeating its mass, overheats the coil; in other words, "strains" it. Coilmakers are unanimous upon this point, although it would obviously be to their interest to maintain the contrary. Clearly, then, this secondary gap is as bad in principle as it is ruinous in practice, its only use being to indicate whether the current is passing or not, or any break exists in the insulation on the coil side of the gap. For this purpose a spark-gap device is handy enough, but since the gap has been shown to be mischievous as a permanency, the wire-ends should be kept normally in contact.

In the foregoing pages we have dissected the trunk, limbs, heart, digestive organs, lymphatics, brain, and nerves of the motor—which respectively correspond to its cylinder, crank-shaft and connecting-rod, piston, combustion-chamber and valve-chest, lubrication and cooling system, current-source and wiring—and thus gained an insight into its physiology. We may therefore conclude by studying what has been aptly termed its lungs, *i.e.* the carburettor, as well as its arterial system, the fuel-feed and connections.

Now, whether internal-combustion motors are really internal-explosion engines or not—a recent theory very much open to question—we know that a mixture of eight to ten volumes of air and one of the vapour or spray of the liquid hydrocarbons used, though inflammable, is not as readily so as one which contains twice this quantity of air. A carburettor, then, is a receptacle constituted so that it generates this mixture in the latter proportions—ultimately at least—or else delivers the fuel itself to the motor inlet in the proportion of one volume to eighteen or twenty of ingoing air. Unfortunately, the majority of carburettors of the former—the generating—type cannot be depended upon to keep this proportion constant at all speeds. The latter, however, in my opinion, are successful in this, as the rate of delivery is mechanically regulated by the speed of the motor itself.

Carburettors belong to three main divisions: vaporisers, atomisers, and the mechanical fuel-distributors just mentioned. To the first division belong bubbling carburettors, those in which the air is made to bubble through a receptacle filled with the liquid fuel maintained at a constant level; surface carburettors, in which the air is drawn over the surface of the liquid, forming a volatile and inflammable vapour as it passes; and wick carburettors. These contain a mass of cotton-wool or a series of wicks, which is kept saturated with the liquid fuel, and carburet the air as it is drawn through the wool or wicks. The first-named variety are scarcely ever used now; but all except the Lanchester wick-carburettor have the great defect of taking all the lighter constituents of the fuel and leaving the heavier, so that the last remainder is so dense that it will not carburate. In the Lanchester device, however, the wicks are kept separate from the fuel receptacle, a small hand-pump taking the fuel up from the bottom of the latter, so that the denser constituents are used first. Furthermore, they all require a shield of at least two sheets of wire gauze in the induction pipe to prevent a back fire exploding them. This creates resistance to the cylinder-suction, and consequent "wire-drawing," *i.e.* incomplete charging, which reduces the pressure in the cylinder and wastes power.

Atomising carburettors constitute by far the largest class at present, despite the numerous defects inherent to the system on which they work. Their chief advantage, however, is that they take the fuel as it comes, without leaving any devolatilised liquid behind. Indeed, many of them can be adjusted to use petrol or alcohol of any density; or even paraffin after preliminary engine warming by a few minutes' run on petrol. But as a fine jet through which the fuel is delivered into a mixing chamber is their most salient part, it will be seen that they may be readily choked, either by foreign matter in the fuel or by deposits of a waxy nature. Again, their adjustment in many instances is a matter of extreme delicacy, failing which, the fuel-supply will be too profuse or too scanty. And —worst fault of all—the majority, unless provided with an auxiliary air-inlet, which is often more or less complicated, will not generate the mixture in constant proportions at varying speeds, giving too rich a mixture at high speeds, which, if corrected, renders the mixture too poor at low ones. Furthermore, many of them, in my opinion, absolutely fight against the piston-suction even when working their best, which naturally means wire-drawing and loss of power. Lastly, the best atomising carburettors are rare freezing-devices, and, therefore, unless jacketed with hot air from the exhaust, are liable to re-condense the mixture in a long induction pipe, thus causing extravagant consumption, if not loss of power through incomplete charging.

A lengthy chapter of the present work would barely suffice for the briefest description of the structural details of the atomising carburettors now on the market. Enough, therefore, to mention the essential construction of such devices in their various types. By far the largest number have two chambers, one of which, the float chamber, contains a cork float, or, in most instances, a copper drum or float-ring, which serves to regulate the admission of the fuel in the first place, then to keep it at a constant level in the chamber, and, lastly, to regulate its flow through the jet into the mixing chamber. The float does this in one of three ways. Either it is mounted on a central spindle tapered at the end to fit in the mouth of the supply-jet from *above*, which closes as the float rises with the rise of the fuel, thus taking enough into the chamber for one charge for each cylinder at a time; or else the spindle is free to move and hung centrally through the float on the short end of one or two pivoted levers, the other ends of which engage with the top of the float, so that the rise or fall of the latter causes the spindle to open or close the supply-jet entering *below* the chamber. Or, again, the spindle is mounted solid with the float as before, and its ends held in guides, while the top of the latter engages with one end of a pivoted lever, to the other end of which the supply-valve spindle is attached.

The air, meanwhile, is drawn by piston-suction into the mixing chamber (the top of which communicates more or less freely with the induction pipe), usually through holes regulated in size by a setting throttle or similar device, so as to maintain the due proportion of air in the mixture. Here, again, is a possible source of wire-drawing, which, however, is absent when the air enters freely. As the air rushes up in response to the vacuum created in the induction pipe by the piston-suction, it takes with it a certain amount of the liquid fuel, which, coming out of a fine jet, or series of jets, is immediately atomised to *mix* intimately with the air to form the charge. Here again we note that this is done in two different ways. When the fuel-duct enters through the bottom of the mixing chamber, and projects more or less directly upwards, so that its jets open in the same direction as the air-currents, the latter *suck* the fuel up. This constitutes a sucking carburettor.

But when, on the other hand, the duct enters the mixing chamber in such a situation as to project the flow of fuel across it at a right angle to the inrushing air-currents, the latter *siphon* the fuel spray along with them as they pass the jet. These, then, may be termed *siphon* carburettors. This distinction is not generally drawn, but will be found to have a very marked effect as the former type have a greater tendency, in my opinion, to enrich the mixture unduly at high speeds. This defect (common to both types) has to be corrected by an additional air-inlet, which opens as the piston-speed increases. In one carburettor, however — the Mors—this difficulty is partially overcome by the fact that the mixing chamber has a vertical wall in the middle. This is bored to form the duct, which opens half-way up into one of the two chambers thus formed, each of which has a free air-inlet at the bottom. Thus a rich mixture is made in the first chamber, which immediately unites above the wall with an equal volume of pure air from the other chamber. Some carburettors, too, are designed so that the air-feed is perfectly free at all speeds, while the fuel-supply is throttled as the piston-suction increases. Thus, although the velocity of the air-currents increase with the piston-speed, the proportions of the mixture are kept constant. Such, at least, is the idea, but whether it be correct or not, or whether, on the other hand, the effect of the pressure-fall in the carburettor is corrected merely at high speeds, need not be argued. At all events, the result of either method of regulation is successful.

There is, however, another large class of atomisers which have no float-feed chamber, the fuel-supply being controlled by a large air-valve, mounted centrally in the mixing chamber with a light spring. In some of these—of which the Huzelstein device is the most typical example—the valve-seating divides the mixing chamber into two halves, upper and lower, its spindle being tapered to open or close the fuel-jet, around which are the air-inlets. Consequently, as the suction acts on the other side of the valve, it rises, and the air is drawn in; the spindle, of course, also rising to let in the fuel-charge, which is atomised on the valve, and drawn in with the air to the other chamber. These, as will be seen, are true sucking carburettors. Obviously, also, they need an auxiliary air-inlet to the second chamber if the mixture is to be kept constant. This is provided in the new Chenard-Walcker carburettor. In others—which all work on the James and Lunkenheimer principle—the air-valve is very much like an ordinary automatic inlet valve, and has its seating at the open bottom of the single atomising and mixing chamber.

The fuel enters through a duct opening (at right angles to the free air-inlet) right in the valve-seating itself. Thus, as the air rushes in at the valve-lift, it siphons the fuel upwards, atomising it on the valve. In this case it will be seen that the fuel-supply requires throttling at high speeds, since the valve which controls its flow will be held permanently off its seating, unless the spring be too strong to allow it to open as it should at low speeds. Thus, failing fuel-throttling, the alternatives would be spilt fuel or wire-drawing. Consequently, such provision is usually made; but these atomisers, which are certainly the simplest in existence, work best when screwed on upside down, or, at least, with the free-air opening uppermost. All these atomisers, whether float-fed or not, are gravity-fed in the first place, unless placed on the head of a vertical cylinder of a marine motor, in which case the fuel is pumped or fed by air pressure to the device.

Mechanical distributors are also pump-fed, unless applied to an automobile motor, with the fuel-tank at a higher level. These, as has been indicated already, supply a definite dose of the fuel to a free air-chamber at or near the inlet valve of the motor, the dose being immediately atomised or vaporised by the free air-currents; which, of course, vary in velocity (and volume in a given charging period to a certain extent) according to the piston-speed, while the fuel-dose is kept constant in amount. There are very few of these devices in use, although their vogue is likely to increase, seeing that, so long as the distributing mechanism is not too complicated, they afford the most reliable method of carburetting. The best-known distributor is perhaps the Gobron-Brillié, in which a revolving cone, with small pockets in its face, makes an oil-tight fit in a chamber supplied by a pump beneath, and communicating with an air-induction pipe above; the cone being rotated at such a speed as to expose a pocketful of fuel at each charging period in the cycle. Another is the White overflow distributor, in which device a cylindrical glass feed-cup forms the body. Into the bottom of this three pipes are extended upwards, the openings of the first two being on the same level, while the third, the return overflow, extends a little higher. Consequently, the overflow from the first pipe is drawn into the second—which communicates direct with an air-chamber formed by the air-inlet of the motor—by the inrush of air during the charging stroke. This takes in just the requisite amount of fuel, which cannot be exceeded, as the return overflow pipe immediately takes any excess. The White distributor is mounted on the cylinder head of a vertical motor, but for obvious reasons would not suit a horizontal one.

So much, then, for the lungs of our motor. Now, carrying the anatomical comparison a little further with the induction pipe—corresponding to the respiratory passage of an animal—we shall note, curiously enough, in the first place, (*a*) that in all animals capable of rapid motion, whether short- or long-necked, the respiratory channel is free from abrupt bends; (*b*) that its diameter increases as its length, or is maintained constant as the length is reduced; and (*c*) that whenever the channel is duplicated (as at the nostrils), the length of each corresponds. Thus the diameter of the windpipe of the horse or giraffe is much greater than that of the slower, shorter-necked ox, while in the still shorter-necked lion it is (proportionately to the relative size of the animals compared) quite as large as in the case of the ox. So with the motor, in which every abrupt bend in the induction pipe breaks the velocity of the incoming mixture and creates wire-drawing, the more for every bend; *i.e.* hinders free inspiration.

Similarly—as we saw in the case of the high-tension current—a long induction pipe (unless its diameter is increased in proportion) resists the inspiration of the mixture, and causes it to travel at a higher velocity for a given piston-vacuum in order to reach the cylinder in a given time. And just as no animal can move freely if half-throttled, the motor is semi-throttled or wire-drawn with such a pipe. Moreover, the increased velocity of the mixture, as we saw, increases the freezing effect and spoils the mixture by taking too much fuel, or by recondensing the fuel-atoms before they can reach the cylinder. Again, in a motor with two or more cylinders, unless the inlets to each pair are (*a*) branched centrally from a common induction pipe, or (*b*) branched centrally from the ends of a second branch into the centre of which that pipe leads, or (*c*) each have an independent pipe of equal length to the air- or mixture-supply, the velocity in the induction pipe or branch of each cylinder will increase proportionately as it is further away from the main supply-pipe. Thus it will be more or less wire-drawn, much as an animal would breathe unevenly if compelled to wear a long and closely fitting tube in one nostril and not in the other.

There is a kind of link nerve—I believe in all animals—called the pneumo-gastric, which forms a controlling connection between the respiratory and digestive organs. This—to conclude our anatomical parallel—corresponds in a measure to the governor, which controls the exhaust, or the mixture volume inlet, or the fuel-feed, or both, and in some cases the ignition as well. This device consists of one or more weighted levers, the weighted ends of which are free, while their other ends are hinged to a fixed point, usually a spindle. This, again, is independently rotated, axially, by the motor shaft, or else the fixed point forms part of some mechanism rotated by the latter in any case, such as the cam-shaft or flywheel. The weighted lever or levers are linked in the middle by other short levers attached to a freely moving collar or sleeve on the spindle; or on the crank-shaft, or on the cam-shaft, as the case may be. This collar engages with a series of linked levers which finally actuate the throttle of the induction pipe, or the fuel-feed, and sometimes the ignition as well; or in still other instances the opening of the inlet or exhaust valves.

Such, then, is the mechanism of the centrifugal governor, the most usual device, which, as will be gathered, acts by the centrifugal—flying-out—motion of the weights above mentioned, when the rate of rotation exceeds the speed for which the governor is set. For, as the weights move out or in, the short link levers naturally move the collar backwards and forwards, and the collar motion consequently sets the controlling levers in motion. Nevertheless, the governor is itself controlled by a second set of levers also bearing on the collar, to set the governor at a certain speed or prevent it acting. This is the accelerating motion (in the latter case), and is controlled by a final lever, the accelerator lever or pedal. Formerly, in exhaust governing, the governor was so arranged as to retard the opening of the exhaust valve by what is known as "hit and miss," that is, a mechanical action which prevented the exhaust-lifting rod from engaging at the usual instant with the valve spindle. This method was found to spoil the scavenge, cause condensation of exhaust products, and often prematurely ignite (back fire) the next charge. It was therefore abandoned in favour of governing upon the inlet, but another, though scarcely more satisfactory, system of exhaust governing is sometimes used, namely, that in which the exhaust valve is opened as usual, but held open a little longer.

Now this last method, although it may give a thoroughly clean exhaust, spoils the inlet in one or other of two ways. The piston, of course, is moving independently of any valve-dwelling, and with an open exhaust valve either loses its vacuum or draws back some of the exhaust and causes premature ignition. At best, it reaches the end of its charging stroke with only a diminished supply of fresh mixture. Thus, although no wire-drawing results, the new charge is weakened, or the compression lowered, and power lost.

And with an auxiliary (a.o.) valve in the cylinder head the case is little bettered, as the additional air controlled by a variable tension-spring may well spoil the proportion of the new charge. It may be more direct in its action than when placed in the carburettor, as in recent practice, and may equally eliminate wire-drawing; and by correcting the abnormal pressure-fall in the induction at high speeds prevent too great a flow of fuel into the mixing chamber. But because of its situation in the cylinder head its spring is more likely to lose temper and tension and allow it to open too soon.

We know, again, that an animal may work efficiently, upon occasion, scantily fed, but never when its respiration is checked. This, I think, finds its analogy in the recently introduced system of governing by throttling the mixture. Despite its universal vogue, I question its economy, and still more its alleged origin in steam or gas-engine practice (see page 97). Wire-drawing, of course, results, and the motor is thus equally starved and stifled. Consequently far more power is lost than is required to steady it. On the other hand, governing on the fuel-feed alone is quite as instantaneous and more economical, and because it in no way affects the size of the air-inlet does not cause wire-drawing or condensation by increasing the resistance to the air-currents. Furthermore, being arranged to reduce the feed slightly at high speeds, it not only keeps the mixture in constant proportion to give the best results, but cuts it out further as soon as the motor races.

Now, with an animal, the function of the pneumogastric nerve may broadly be described as indicating whether it is receiving too much food for the exercise it is given, on the one hand; or whether, food and work being normal, it has sufficient pure air. But though it may indicate, it cannot remedy. The animal, unless measures are taken to alter abnormal conditions, simply loses health and working power. If, then, these conditions are such that the animal, though receiving a normal amount of food, cannot get rid of its waste products, the pneumo-gastric acts at once, and ill-health ensues. This is exactly what happens in a motor governed by exhaust delaying. If, again, food and work amounts be normal, but the supply of fresh air curtailed, the same result occurs, just as it does in a motor throttling the air-supply. And naturally, an animal, if both starved and deprived of sufficient fresh air, would lose strength at an extremely rapid rate, and take longer to recover than if it merely had its food reduced.

Similarly a motor, throttled on the mixture inlet, loses its power much more rapidly, and takes longer to pick it up than is at all desirable or necessary to steady it. Yet if the food of an animal, rather "above itself"—like a racing engine—be slightly reduced, though leaving it all the fresh air it needs, it will steady down without losing health or efficiency. Now the condition of "being above itself" is one of the earliest symptoms of too much food and too little exercise, and is caused by slight irritation of the pneumo-gastric. The only remedies, of course, are less food or more exercise. But the latter is just what we cannot give our motor, which is running too fast as it is. Therefore our most direct method is to reduce the fuel-feed only. Now our analogy has at least been shown to be appropriate in regard to exhaust-delay and air-throttle governing, both of which have been proved by experience to be wrong methods. So, I venture to predict, will mixture-throttling be proved wrong; indeed it is already discarded in many recent instances in favour of fuel-feed-throttling, or varying the lift of the inlet valves; or holding them open longer to a free supply; or by cutting out cylinder by cylinder by keeping them open, like an animal going to sleep, ceasing to work, but as free to breathe as ever.

Still, any such system must introduce further mechanical complications, and, speaking for myself, I should imagine that the most reasonable method of controlling an animal was neither to stifle it, stint it, nor allow it to doze even for a moment when it was supposed to be working, but simply to rein it. So with a motor: the system of reining it from the cam-shaft and governor by advancing or retarding the duration merely and *not* the extent or time of the lift of the inlet valves, would appear to be the most in accordance with the true conception of its physical nature, to say nothing of being simpler mechanically; timing the ignition to correspond, or not, as found best in practice. The piston-suction is not varied one iota by the change, nor the velocity of the mixture. Therefore a charge, unaltered in quality but merely in amount, must be aspired; with proportionate power per impulse at all speeds. Such is the resulting range of speed control that the motor, so to speak, has its hocks under it at all times. Then, again, having fitted a good, automatic, atmospheric-pressure-controlled carburettor that breathes as the piston breathes, why not let it alone? Why complicate the working of a carburettor by linking it up with the water circulation, thus making its good behaviour depend on the condition of the pump? It is only making a heavy, inelastic medium, water, control a light, elastic one; thus we may get over-control at times. Furthermore, why link it mechanically with a lever system, the joints of which may break and must wear? Surely the plain snaffle action of a push-shaft and skew-cam is better than all the physical or mechanical gag-bits and bearing-reins ever invented.

CHAPTER V

TWO-STROKE INTERNAL-COMBUSTION MOTORS—SILENCERS

IN the previous chapters the reader will have fairly grasped the constitution and working of internal-combustion motors of the four-stroke type. But the details of these have been given somewhat fully—and to a certain extent, from a constructional point of view—for three reasons. First, because most of the essential parts and their function, as well as the systems of ignition, lubrication, cooling, and carburation, are the same in two-stroke motors. Secondly, because their constituent parts, stationary and working, are very similar to those of the steam motors used for automobile work. And, thirdly, because the discussion of electric ignition has formed some slight introduction to the methods of current-production in electric motors. We find, however, that the internal-combustion motor of the two-stroke type, though subject to the same physical conditions and possessing most of the same parts as the four-stroke engine, nevertheless differs materially in its constitution. It is not quite certain who was the first to discover this cycle, but the weight of evidence is in favour of James Robson, of Birmingham, who took out a patent for such a motor in 1879, and put it on the market in an improved form two years later.

In this cycle an impulse is given to the piston—in other words, a working-stroke occurs—*once* in each revolution of the crank-shaft. The system, when introduced by Robson, was entirely novel, as will be seen from the description of its construction and operation. It has, of course, a cylinder, piston (and in stationary types, as a rule, a piston-rod with a pin or block sliding in guides, known as a crosshead), a connecting-rod, crank-shaft, crank-case, and flywheel. But, in common with the majority of its later adaptations, the two-stroke motor has no valves, with the exception of an air-valve in its carburettor, a throttle in its transfer-duct—of which presently—and sometimes an auxiliary air-valve in its crank-case. Instead, the piston acts throughout the cycle as a combined charge pump and slide-valve; in its latter function covering and uncovering certain openings in the cylinder walls during its travel. These openings—which are known as *ports*—correspond to the valve openings in other motors. There are usually two of these, the lower or charge inlet being so placed as not to be fully uncovered until the piston has reached the end of its outstroke. The other, the exhaust port, though placed on a level with, and opposite to, the inlet port in some cases, is placed just above and opposite in the majority of examples.

In Robson's cycle the inlet port constitutes one end of a transferring duct leading from a third port just beyond the limit of travel at the *front* end of the piston. This last is formed in the wall of an extension of the cylinder, which is closed to form a pumping-chamber, the piston-rod passing through a packed gland or stuffing-box. Into this chamber, then, the gaseous charge is drawn by the suction of the piston at its *first instroke.* But although no work is done on the *first outstroke*, the piston compresses the charge in the pumping-chamber. This compression lasts until the inlet port is uncovered, upon which the charge rushes up into the cylinder behind the piston. On the second instroke it is again compressed, and fired at or near the dead point—the other end this time—of the piston-travel. At the same time, however, the front end of the piston has drawn a fresh charge into the pumping-chamber. Ignition having taken place, the consequent expansion of the ignited charge drives the piston outwards in a working stroke, which is also a compression stroke on the other side of the piston. As soon as the exhaust port is uncovered—near the end of the outstroke—the ignited charge escapes as exhaust. Immediately afterwards, the inlet port is uncovered, and the new charge rushes in; the same operations being continuously repeated during every revolution of the crank-shaft. This constitutes the Robson two-stroke cycle, and it is impossible to conceive anything simpler.

But this very simplicity has proved highly treacherous to almost every innovator except that eminent engineer, Mr. Dugald Clerk, who used a separate charging pump —worked at even strokes with the working cylinder —instead of using the front end of the cylinder, as a pumping-chamber. He, so it is said, was the next to follow Robson; nothing further of any importance being done until Joseph Day, of Bath, patented (in 1891) a motor in which the cylinder was practically shortened to little more than the length of the piston-

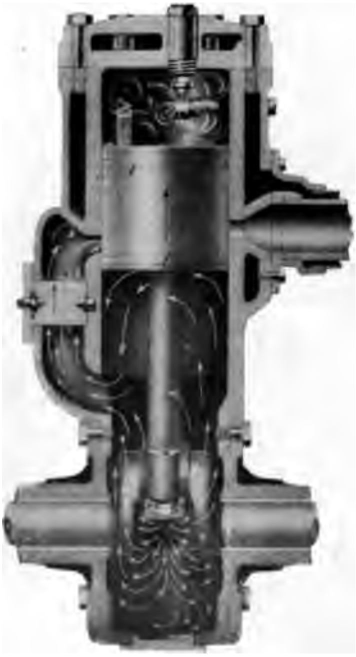


FIG. 9

INSTROKE: SHOWING (*a*) INDUCTION BELOW PISTON, AND (*b*) COMPRESSION AND IGNITION ABOVE

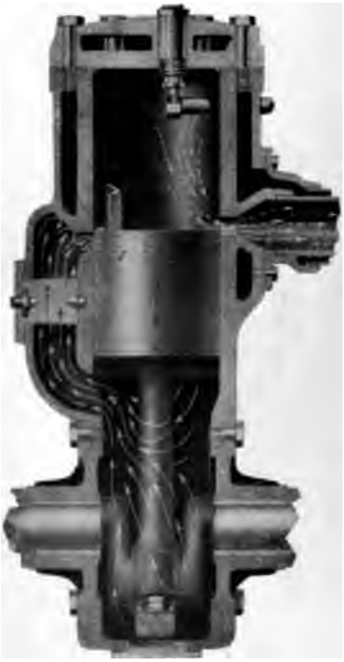


FIG. 10

OUTSTROKE: SHOWING EXHAUST AND FIRST COMPRESSION

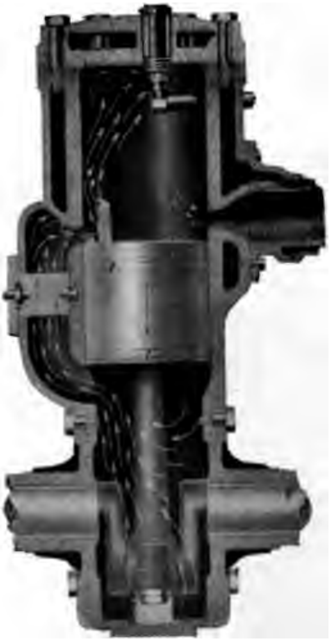


FIG. 11

OUTSTROKE COMPLETE: SHOWING TRANSFER OF NEW CHARGE, *THEORETICALLY*

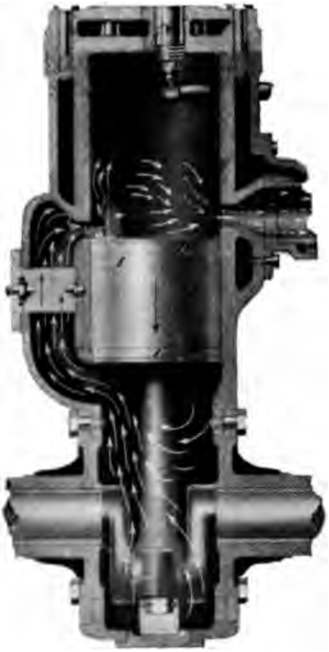


FIG. 12

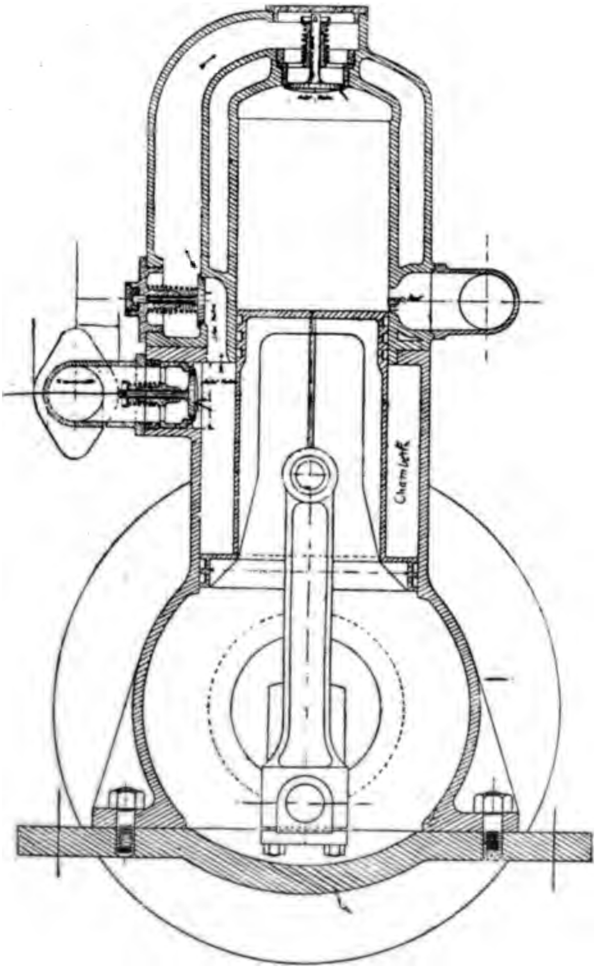
OUTSTROKE COMPLETE: SHOWING WHAT ACTUALLY OCCURS DURING TRANSFER OF NEW CHARGE

yet; for although various patents exist for two-stroke compound motors, it does not appear that any have been manufactured. Nevertheless, compounding is said to have been successfully achieved in the Roser-Mazurier and Graham-Fox four-stroke motors. In the first of these the exhaust of two cylinders is led into a larger central one of twice the size, the piston of which receives a working impulse during each revolution of the shaft, as in a two-stroke motor.

Motors of the Day type have, nevertheless, been extensively adopted in Great Britain and the United States for marine work, aboard small launches and yachts in which neither high speed nor power above 8 h.p. or so are required. At all events, they are said to fail at high speeds or with varying loads, which has led to their comparative neglect for autocar purposes, except by one or two manufacturers in the United States. But since they have been improved in detail so as to render them undoubtedly reliable for launch work, one would imagine that any disabilities under which this cycle is supposed to labour are not so much inherent as due to faults in design in various examples. There is also the Bichrone two-cycle type, in which the gaseous charge is pumped into the working cylinder —through a non-return a.o. valve—from an auxiliary cylinder set at an angle of 45°, so that the pumping piston may be connected to the same crank as—and work synchronously with—the working piston. The disadvantage of crank-case compression is thus eliminated in this type, and very little weight is added, but the whole has a cumbrous appearance.

Another variation is shown in the two-stroke motor recently invented by A. F. Evans, of Cambridge. In this, crank-case compression is used, but only for air. The carburation constitutes the novelty, in fact; as the air passes through the transfer lead in the usual manner, but passing the mouth of a narrow tube midway, which leads from a small petrol receptacle attached to the cyclinder body, it siphons up a sufficiency of fuel to form an inflammable charge, the petrol being atomised as in an ordinary perfume sprayer. The inflammable charge then enters the combustion-chamber from above through a non-return a.o. valve, as in the Smalley motor. The Underwood paraffin motor, as well as that of Lucas (7539 of 1902), approximate to this system.

The latest application of the two-stroke cycle—one, furthermore, which is entirely novel in design and operation—is the Heasman motor, now being manufactured by the Noble Motor Company, of Blackfriars, London. It operates, not by crank-case compression, but by a vacuum created in the lower half of its cylinder, which draws in the new charge as well as scavenging the exhaust. The cylinder is cast in two halves, upper and lower, with narrow and wider diameters respectively. The former is the working cylinder, while the latter—the broader one—is the vacuum-cylinder, and has a carburettor opening into it as well as a short transfer lead. In both of these travels a long, double-ended trunk piston of special construction, with two diameters, corresponding with those of the cylinders. Its narrower diameter is extended downwards into the lower cylinder for all but an inch and a half of its length, widening from that point to the bottom of the trunk to fit the lower cylinder. It thus forms a double-ended piston, carrying rings at both ends. But as its narrower



THE HEASMAN TWO-STROKE MOTOR

part extends for some three-fourths of its length, it follows that a large annular chamber is formed around it in the lower cylinder, the capacity of which varies with its travel. This constitutes the vacuum chamber. The exhaust valve is in the usual situation, at the end of the piston-travel; but the induction system is distinctly novel in mechanism and working. It consists, firstly, of a non-return valve opening from the induction pipe into the upper part of the lower annular chamber. Above this, the short transfer lead communicates by a second non-return valve (opening the opposite way) with a larger transfer or storage lead, which runs upwards over the top of the working cylinder and opens downwards into it through a third non-return valve, the inlet-valve proper. Now, during the first four strokes at the start, the motor acts partly on the four-stroke principle; that is, the charge is drawn into the annular vacuum chamber during the first stroke by the lower end of the double piston. The latter then drives it upwards into the storage lead through the second valve during the following instroke; the charge being next drawn into the working cylinder during the second outstroke, which also draws a second charge into the vacuum chamber below at the same time. The first charge is then compressed and fired at the end of the second instroke; and the two-stroke cycle now begins; for the lower end of the piston, during the second instroke, drives the second charge up into the storage lead (where it is stored at a pressure of two atmospheres) at the same time that the upper end is compressing the first charge to six atmospheres before ignition. The difference in the two pressure-rates of course keeps the inlet valve above tightly closed. But the moment the next—the first working—outstroke is complete, and the pressure of the exhaust gases has fallen below two atmospheres (during which time a third charge has been drawn into the vacuum chamber below), the pressure of the stored charge opens the inlet valve and enables the charge to completely fill and scavenge the working cylinder. The third charge is then driven up to take its place in the storage lead during the next instroke; at the end of which ignition again occurs, and the two-stroke cycle is continued; as the outstroke, of course, draws in another charge below; which again replaces the third charge in the storage lead, and so on.

It will therefore be seen that the Heasman motor, apart from the novelty of the cycle, possesses the advantages of complete scavenging of the exhaust—in which respect the majority of Day-type motors fail at high speeds and varying loads—and complete filling of a clean working cylinder without the possibility of any of the new charge escaping into the exhaust. Withal the combined cylinder is no longer than that of an ordinary Day-type motor; and—since no compression takes place in its crank-case—this can be made as open and accessible as the crank-case of any four-stroke motor, thus rendering the whole construction some 30% lighter. Another result of this gain in accessibility to working parts is that the crank-case never needs removing from its bed, the cylinder only being removed for overhaul or repair. Other claims made are exceedingly high power at low speeds, low fuel consumption (·55 of a pint of petrol per b.h.p. said to be have been made at the test), and freedom from vibration at all speeds. Should future working substantiate these, we may see a two-stroke motor at last applied to autocars with success; but in any event, the Heasman motor so thoroughly constitutes a new type that the present work would be incomplete without its detailed description.

All internal-combustion motors are fitted with a device known as a silencer, which, as its name indicates, is used to silence—or at least muffle—the noise made by the exhaust gases as they pass out at the end of each working stroke. This device has not been mentioned before, because—although universally used for obvious reasons—it is not essential to the efficient working of a motor, and indeed, unless properly designed, detracts from its efficiency by setting up back-pressure. The noise of the exhaust is caused by the sudden liberation of gases, previously confined at a high pressure, into the surrounding atmosphere without being gradually expanded, *i.e.* having their pressure gradually lowered. The silencer, therefore, consists of a chamber in which that pressure is lowered as gradually, though rapidly, as possible; any break or sudden arrest of this process setting up back-pressure into the motor—*i.e.* incomplete clearance or scavenging of the gases, which, of course, prevents the normal volume of the new charge being inspired during the following suction stroke. And since the exhaust and induction occur once to twenty times every second, it will be seen that anything which hinders the former being got rid of with the utmost rapidity and thoroughness, must materially upset the efficiency of the latter, as the inability to aspire a normal charge naturally lessens the power of the next working stroke. Consequently the less back-pressure set up in the silencer, the more efficient will the motor be. Indeed, a perfect silencer should muffle all exhaust noises without setting up any back-pressure whatever.

Silencing is achieved by two principal methods, dry and wet, or by a combination of both. In the first method the object is to lower the velocity of the gases —*i.e.* the pressure impelling them—simultaneously with deadening the noise. This is effected first by gradual expansion in a large closed chamber, usually of cylindrical form, and divided up into a series of freely interconnecting expansion chambers; and, secondly, by turning the stream of the gases at a *right angle* to its last direction perpetually, and splitting it up into smaller streams. These chambers should increase in area from within outwards, and the innermost one should at least be of larger diameter than the exhaust inlet pipe. Furthermore, the outlet from each, whether by a single passage or a number of perforations made so as to split up the exhaust stream, should be larger than its inlet, to avoid back-pressure. The second method—the wet one—is to condense the gases in cold water or some deodorising fluid in the outer chamber of the silencer. In this case, too, it is important that there should be at least one central expansion tube of larger diameter than the exhaust inlet for the gases to pass into *before* condensation, so that expansion may be well in progress, and that there may be something interposed between the inlet and the condensing fluid to prevent them recoiling, so to speak, from the condensation and returning to the exhaust pipe. This is provided by the walls of the first tube or chamber; for once the gases have passed through its perforations, it is easier for them to expand still more in the larger condensing chamber than it is to return and set up back-pressure. They are therefore condensed in the latter, and then cannot return.

In the first method of plain, dry expansion and exhaust-stream-splitting, if there be only one large outer chamber round the central one, it is important that the final outlet should be small and indirect—such as is afforded by a supported pipe of small bore; that is, if the secondary essential, complete silencing, is to be achieved. For obviously a large direct outlet would afford the readiest path of direct expansion to atmospheric pressure, and the gas streams would rush towards it at once with their velocity only once reduced. And as velocity presumes pressure, it follows that their noise would be very slightly diminished at such an outlet. Also, the valuable effect—even and general expansion—of the extra size of the outer chamber would be utterly lost. Thus the reasons why the combined system—*i.e.* water-jacketing the expansion chambers—is the best will be apparent; seeing that not only is the exhaust stream split up and gradually expanded, but its velocity is reduced, because the condensing effect of the cooling water-jacket has reduced the heat and therefore the pressure. Again, the water-jacket itself—which is supplied from the motor cylinder-jacket—helps to deaden the noise of each successive expansion. Also, fewer expansion chambers are required, and the whole device will be more compact.

There are, however, many so-called silencers which merely consist of one expansion chamber, with a series of internal ribs, flanges, or baffling plates, which simply turn the course of the exhaust stream without reducing its velocity in the least. Others, again, are filled with such matter as pebbles, steel shavings, or scrap wire.

These are useless also, for the same reason, even though they may split the stream to some extent. But both are only successful as silencers in proportion as they set up back-pressure, and get terribly hot in working. For this reason, too, the expansion chambers of dry silencers should not lead into one another in abrupt bends, bassoon-fashion, as such bends constitute so many baffles. Easy bends, with bell-mouthed openings, or, best of all, free perforation, is the best means of communication between one chamber and the next. There is, nevertheless, a type of dry silencer with yielding baffles which is thoroughly efficient, this being the rotary silencer, resembling an ordinary rotary bellows, pump, or fan—such as that used for mine-shaft ventilation—in miniature. The rotar in this is free to revolve, and the exhaust stream is broken up by being pocketed in the spaces between the blades, the latter acting as yielding baffles which check its velocity. Further, as the stream is turned round at a right angle from its course, it is effectively silenced, and the sucking action of the rotary, acting even faster than the exhaust stream pressure, aids materially in scavenging the cylinder.

The best dry silencer I have ever seen, so far as design is concerned, is the Dunlop acoustic muffler. In this a plain straight pipe, with two openings in its walls — opening into expansion chambers — communicates with the exhaust at one end and with the open air at the other. Now in such a tube the vibrations of the sound waves going through intersect each other at points known as nodes. Here their vibration ceases temporarily, but is greatest at the antinodes or loops between the nodes. At these antinodes, however, the openings into the expansion chambers occur, in the Dunlop device; the two chambers being formed by a single diagonal division—through which the tube runs—from top to bottom of the silencer. They thus act as silencing chambers; and there being no obstruction in the tube, the exhaust passes out in one continuous, noiseless stream, any back-pressure being out of the question. Similarly the best water-jacketed silencer, in my recollection, resembles an ordinary Scotch boiler with domed chambers at its inlet and outlet. The combined area of its flue-pipes — round which the water circulates, as in a boiler—is about twice as great as that of the exhaust pipe from the motor, thus giving ample opportunity for unrestricted expansion, passage, and condensation. In this case, however, it is essential that the final outlet to the air should be large and direct, so as to give free exit to the exhaust streams, which have been split in the water-cooled flues and condensed to atmospheric pressure, or thereabouts.

CHAPTER VI

STEAM MOTORS

SECOND alone to the internal-combustion motors described typically in the foregoing three chapters, we have the various makes of steam-motors used on automobiles, with their essential boilers or steam generators of one kind and another. These motors—or, as they are generally termed, engines—as applied to road carriages, are either single or double-acting, simple or compound. In all, the essential parts are very similar to those of an internal-combustion motor; that is to say, that all have cylinders, pistons, connecting-rods, and a crank-shaft to receive the power generated on the one hand, and to turn it into mechanical work on the other. But the main physical differences between these and the latter are that each piston receives one impulse (and in double-acting examples, two) during each revolution of the crank-shaft, and that all can be reversed; that is, made to turn the crank-shaft in an opposite direction to that in which it is rotated for forward propulsion. A third difference is that their average working rate of speed is far lower, and therefore does not require to be reduced by means of special gearing between the engine and the transmission shaft, all changes of speed being effected by regulating the amount of steam admitted to the

cylinders. Thus, not only is the flexibility—*i.e.* range of speed—of these steam engines rendered much greater, but no power is lost further than the small percentage lost through friction on bearings, etc., during direct transmission; which loss is, of course, common to all motors.

A fourth point of difference is that this speed reduction, although effected by regulating the amount of steam admitted, has not the wire-drawing effect of throttling the amount of mixture to the cylinders of an internal-combustion engine, seeing that the steam, being supplied from the boiler under a pressure varying from six or seven to twenty atmospheres, is naturally highly expansive, whereas a gaseous charge as it leaves the carburettor is only expansive so far as it is volatile. And yet a fifth difference is that the steam—unlike the ignited inflammable charge of an internal-combustion motor—does its work at a comparatively low temperature; the one varying from 170° to 190° C.—and even when superheated only reaching from 350° to 540° C.—while the other, as we know, is about 2,000° C. Consequently, so far from there being any need to cool the cylinders—lest, despite all lubrication, they overheat, burn their valves, and seize their pistons—means have to be provided in the case of the steam motor—such as lagging with asbestos encased in metal or hardwood, or even jacketing the cylinders with superheated steam—to keep the heat in, so that they may not part with it by radiation to such an extent that the steam becomes partially condensed.

Still another physical difference is that of the expansion effort. Steam, instead of acting like an explosion, is practically constant as to its pressure, this only gradually increasing against the resistance. On the contrary, the maximum expansion effort in an internal-combustion motor occurs at the beginning, and is only maintained for about a fifth of the stroke, rapidly decreasing towards the end. Thus, if the work to be done is too great, it will be unable to overcome the resistance; and although it may break a connecting-rod, wrench the crank-shaft, or even burst the cylinder, will vanish as the pressure is reduced to that of atmosphere. Thus, even if no structural damage be done, the motor will stop unless the overload be removed. The maximum effort will have been expended; and even were it conceivable for still other expansions to be produced in a motor that had ceased performing the normal operations of its cycle, the effort of each would have no better success. The only effect would be the gradual disintegration of the structure. But the steam-expansion, on the other hand, continuously reinforced from the boiler in which normal working conditions of fuel-heating and evaporation of water are being maintained, will positively overcome the extra load, or burst something—either a cylinder head, a steam connection, or the boiler itself—*inevitably;* that is, if these conditions be continued and no outlet provided, such as a safety-valve, for the steam to escape. This because under such circumstances the pressure of steam—and therefore the effort—is cumulative. This quality of being able to make an extra effort, called elasticity—too often confounded with that of flexibility, of which it is nevertheless a factor to some extent—constitutes in practice, perhaps, the chief advantage held by the steam engine as against the internal-combustion motor.

Structurally, again, still greater differences exist be-

tween the former and the latter. For one thing, since the compression of the power-element is produced externally, and though continuous, is lower, and acts throughout, as has been shown, at a far lower temperature, we are not hindered, for mechanical reasons, from using both sides of the same piston alternately, so as to obtain two impulses in each cylinder for every crankshaft revolution. Engines of this type are known as double-acting. In single-acting engines, on the other hand, the cycle is the same in each cylinder as in a two-stroke motor; and trunk-pistons, differing but little from the piston of one of the latter, are used, with similar connecting-rods. To resume, the piston of a double-acting cylinder consists of one or more solid discs—or, at most, a disc with a flange vertically truncated downwards—carrying the usual packing rings. Such a piston, instead of carrying the usual gudgeon-pin with a connecting-rod, is bolted centrally upon, and rigid with, one end of a rod—the piston-rod—which moves up and down with the piston-travel through a packed gland—the stuffing-box—in the closed front end of the cylinder. Outside, it is attached centrally to a pin—the cross-head—which is held between two sliding guide-pieces, or forms the upper part of a single-sliding block. To this pin also, but on either side of the piston-rod end, the small end of the connecting-rod is attached by forked arms or jaws.

Again, since steam, after it has done its work in one cylinder, still seeks further expansion, it can be used again to give a further effort in a cylinder of larger diameter. This is called compounding. At a high original pressure still other cylinders can be used in triple or quadruple expansion. These last, however, if

only for reasons of bulk, are not used for automobile purposes. But even in low-powered engines the compound system, for some reason or another, is comparatively rarely used in automobile construction, probably owing to some belief on the part of manufacturers that the greater bulk of the low-pressure cylinder offsets its undoubted economy. Personally I disagree with this idea, although admittedly among the minority, in view of the mass of working conditions, and the circumstances governing them, as well as the variations of road work. Principally we desire to eliminate bulk; also, over-powering under normal conditions. Yet we must have reserve power for emergencies. For instance, on a level road the normal horse-power of the usual engine is generally more than sufficient, but the moment a steeper or stickier ascent than usual has to be tackled nothing beyond the normal effort is available with two or more high-pressure cylinders. Thus speed appreciably slackens, the last thing desirable on a heavy road. Either this, or we must have a higher-powered engine than we need under normal conditions. This means slightly more bulk and greater expenditure of fuel and steam. On the other hand, using the compound system, we can have an engine of moderate power for ordinary working conditions, and arrange it so—by fitting a special device (a simple two-way throttle-valve controller)—that the larger low-pressure cylinder can be turned into a high-pressure one at once by actuating this controller, which leads the steam directly into it. Thus as emergencies arise we can increase the available power by at least a third. Speaking from memory, I can only recall two steam cars, the White and the House, which are fitted with a compound engine, to

which fact, in my opinion, the phenomenal success of the former, both in all-round reliability under the most disadvantageous road conditions and in hill-climbing power, is largely due.

Now, owing to the constant pressure of steam—that is, under ordinary working conditions—it happens that it can be "fed," so to speak, through the leads to the cylinders in varying quantities according to the speed desired. The feeding mechanism is, of course, the valves, which are of three kinds—slide, piston, and poppet respectively. The first kind is the most varied as to type, one variety being like a cup with flanged edges, which open or cut out the leads to or from inlet or exhaust ports; while in another form a revolving disc with coinciding openings is used. In fact, any device which, when actuated, opens or cuts out the leads, admitting the steam (*a*) to one side of the piston or another in one cylinder, or (*b*) to another cylinder, compound or otherwise, or (*c*) allowing it to pass to the condenser as exhaust, by (1) a reciprocating—to and fro—or (2) a rotary *sliding* motion, or (3) an eccentric motion, may act as a slide-valve. Piston-valves, on the other hand, are small solid pistons, mounted two on a rod in the case of double-acting engines. These, reciprocating in a smaller cylinder—the valve-chest—which the steam enters from the steam-chest, connected with the supply-pipe from the boiler, open and cut out the leads to and from the working cylinder in the same way. Poppet-valves have already been described in the chapters on four-stroke internal-combustion motors. They act, as may be supposed, much in the same style in the single-acting steam engines, to which they are apparently only applicable, with the exceptions that each one of the pair, inlet and exhaust, that are fitted to each cylinder opens and closes *once* during each piston cycle, and that the timing and degree of opening and closing are both varied through a wider range.

The mechanism, nevertheless, which actuates the valves of a steam motor is entirely different from anything having a similar function which has been discussed hitherto, except in one or two cases, such as the Gardner-Serpollet and "Jaxon" engines, which bear a striking resemblance to internal-combustion motors. Such mechanism necessarily differs, because the timing of the movement of the valves has to be varied through the range of the piston stroke from some 10 per cent. to about 85 per cent. of the travel. This, in order that so much more, or less, steam may be fed to, or passed from, the cylinder; the amount, as will have been gathered from the previous paragraphs, varying the speed. Consequently, be the amount what it may, the mechanism is *always moving* at greater or less speed throughout the cycle; the valve-spindle, or tripping-rod, as the case may be, also constantly moving; although, as has been said, the range of movement and the speed vary. But there is no sharp action followed by a brief period of quiescence, as with the valves of a four-stroke motor, the valve mechanism of which is actuated by a cam, constantly rotating, but *intermittent in action.* Were it otherwise, the continuous and varying action of the valves, which gives such extensive speed-range, would be lost, and with it the whole advantage gained from the supply of a power-producing medium at constant pressure from without.

Consequently, instead of a cam, an eccentric, which gives constant motion throughout the cycle, is used as the basis of the valve-actuating mechanism. This, instead of being formed on a half-time shaft, is usually situated on the crank-shaft itself, and in any case rotated at even turns with it. Furthermore, the eccentric must be of such a size as to move the valve throughout the range of its designed travel, or (according to the setting of the intermediate mechanism, which will be discussed presently) to any required degree, no matter in which direction it may be rotating itself. A crank, it would be thought, would do this, since a continuous reciprocating motion is required for the intermediate mechanism, if it is to impart the desired motion to the valve. Nevertheless, a crank will not do; first, because this motion has to be duplicated in a very narrow space—for a reason that will appear—and secondly, because of the said duplication, it would be well-nigh impossible to form two cranks in that space. Under these circumstances, we can best obtain the desired motion by keying (or forming) two eccentrics on the shaft side by side, in suitable relation to each other, to give a double crank motion when each is held in a freely moving collar—the strap—which forms, in its two halves, the "big end" of a connecting-rod. Obviously, even were the intention of the whole design not against doing so, it would be impossible to fit such a rod on an intermittently acting cam.

But the reason why two such rods—and therefore two eccentrics—are required to act in such a narrow space, is that their other ends are connected to a single cross-link in what is known as a Stephenson link-motion. This link consists of a slotted segment of kidney shape, and is held concave [illegible] the rods which are pivoted to [illegible] formed on one end of the valve-lifting or tripping rod, or, in most instances, a pin held between two jaws, similar to the connecting-rod attachment, moving freely in the slot. These attachments, by means of slight bends on the rods, chiefly, are made at one side of the link. On the other, it is attached at one end to a small arm, the other end of which is connected to a pin held (opposite the other end of the link) in a sleeve; which again, forms one end of a T-shaped lever. This lever is rigidly secured to a transverse rocking-shaft, that is, one capable of slight axial rotation. The other end of this pin is secured in the same way to an arm attached as before to a similar link-motion, the valve-actuating mechanism of the second cylinder. Thus it will be seen that this pin connects both mechanisms, and that rocking the shaft pulls the links by their arm-attachments to the pin—in or out—thus altering the position of the valve-rods in their slots. Now, one of the two connecting-rods in each link-motion is longer than the other, therefore the angle of the link with its valve-rod is altered as it is moved in or out, that is, the end of the link is lifted or lowered. This increases or reduces the length of the valve-rod stroke, while maintaining the continuous reciprocating action. Similarly, by rocking the shaft so that the relation of the links is reversed, a momentary dwell occurs in the valve-rods midway in their travel. This causes a similar dwell in the pistons (as the steam exhausts without moving them), and consequently in the crank-shaft rotation. But so soon as the link-reversal passes mid-point, the exhaust is closed by the valve, the steam again fed to the same side of the pistons as at last admission, the piston action reversed, and with it the rotation of the crank-shaft. This constitutes the reverse.

Numerous other valve-gears are used for the engines of steam-driven vehicles, such as Joy's and Walschaërt's, etc., but the Stephenson link-motion has been described, being the one which is most generally found, especially on the light and medium types of steam car. We find, however, in the majority of single-acting engines in which poppet valves are used, that the cam—or rather an eccentric used as a cam, not the typical one—is employed to lift the valve-spindles and their rods. But these special cams are coned literally more or less, so as to vary the lift and cut off, to cease to lift, and to lift again in order to reverse. Such, for instance, is the construction of each eccentric cam on the central cam-shaft in the well-known Gardner-Serpollet steam motor, all these being mounted together in one long undulating sleeve-like cam, keyed rigidly on the shaft. In early constructions this cam and shaft were made in one solid forging. This composite eccentric cam then acts upon rollers mounted on lifting rods, which again act upon the spring-controlled valve-spindles exactly as in a four-stroke internal-combustion motor, the only difference being that the action is more or less continuous, not intermittent.

The cut-off, neutralisation, and reversing are obtained, as will be imagined, by sliding the shaft lengthwise in its bearings, and in the spur-gear by which it is driven, the shaft being square-sectioned at that end, so as to slide freely in the gear while rotating. This spur-gear is driven at even turns by a similar gear on the crank-shaft common to the connecting-rods of the oppositely mounted cylinders, which are arranged [illegible] threes, each pair having one admission pipe to the inlet-valve chest in the centre of their heads, and one exhaust pipe branched from the ends. Nothing, in fact, could be less complicated than a Gardner-Serpollet steam outfit, were all its parts as simple as the engine. There are other systems of cylinder arrangement and valve-control, but since the above examples typify the principles on which the majority of reciprocating steam motors work, there is no need to enter into the mechanical differences between each of the numerous makes, such as the Toledo, Mason, Weston, White, House, and Serpollet (described in the foregoing paragraphs in general detail), Chelmsford, Chaboche, Miesse, Thornycroft, Le Blant, Scotte, Reading, and one or two others used on light and medium cars; or the "Lifu," Simpson-Bodman, Kecheur, de Dion-Bouton, Coulthard, Musker, Leyland, Bayley, Foden, and Clarkson-Capel, among heavy steam waggons and lorries. These details, interesting enough, but too voluminous for the purposes of this book, may nevertheless be obtained in any of the larger standard works on the subject.

Although rotary motors certainly represent the only avenue of marked advance in steam practice, it is generally admitted that hitherto, despite their theoretical economy, they have not proved satisfactory. Mention should however be made of one, the Nègre, which may be described as semi-rotary, because though its working parts reciprocate, it is practically rotary in action, as there is no dead point. Furthermore, it is compact to a degree, and possessed of a very great range of elasticity and flexibility, its horse-power varying from 8 to 20—at pressures of 140 lbs. to 215 lbs. per sq. in.—through a speed range varying from 200 to 1,000 revolutions per minute. It consists of four short cylinders (with single-acting, short-stroke, solid pistons) arranged opposite each other in the form of a cross, as the arms, so to speak, of a large central cylinder, which acts as a shaft casing, steam chest, valve chest, and reversing-gear case in one, the portion behind the working cylinders acting in the last three capacities. The inlet and exhaust-leads to each cylinder open into this common central steam chest, and are opened and closed by one of two flat annular flanged slide-valves, both mounted on one eccentric on the shaft, the inner one being otherwise unattached. These valves consequently have two motions, as they slide to and fro against the leads, and rotate to each cylinder in turn, the inner unattached one actually opening and closing the leads with its flanges and body, while the outer slide moves in similar fashion to open and close holes cut in the body of the inner one. This outer slide is secured to a disc plate—through holes cut in the latter—which is mounted on a free sleeve-bearing on the shaft, so as to enable it to rotate with the slide-valves. This bearing again carries a short stud, on which a bell crank is pivoted; one arm of the bell crank being secured in a slot on the disc plate, while the other is connected by a short rod to a collar or sleeve, which is free to slide along the shaft, but rotates with it. Furthermore, one end of a short lever is formed into a stud entering this collar, while the other end is "fulcrumed" on a cross-arm entering the gear-case from the control lever without. Thus it will be seen that moving this lever slides the collar along, which actuates the bell crank, which again moves the plate and alters the relation of the slide-valves with each [illegible] the [illegible] lead of the steam, cutting it out, or reversing it. The slide-valves, too, are arranged so that when the steam is admitted behind one piston, the exhaust takes place in the opposite cylinder, while the two intermediate pistons are in the middle of their working and exhaust strokes respectively.

Again, the rods from each opposite pair of pistons meet rigidly in the centre of an elliptic frame. Thus the two frames reciprocate across each other's plane; and as they both surround a roller bearing, mounted on an eccentric pin—practically a crank-pin—on the end of the central shaft, rotate the latter as they reciprocate. Now since the valves—as will be seen from the foregoing—admit the steam to each cylinder in turn, the steam effort circulates, so to speak, around the cross. This produces continuous piston movement acting in the same rotary fashion, the result being that there is no dead point at any period of the shaft rotation. Moving the control lever from one end of its guide-plate to the other, as has been already indicated, reverses the relation of the slide-valves, the steam lead, and consequently the shaft rotation; intermediate positions giving all variations of steam admission, while holding it at the middle point—corresponding to "mid-link"—causes the dwelling between changes of rotation, or if maintained, the stopping of the motor. And since the measurement from the outside of one cylinder head to that of the one opposite is only 16 inches—cyli[illegible] bore and stroke being 4 inches and $2\frac{3}{8}$ inches [illegible]ly—while the measurement from the front o[illegible]ral cylinder to the outside of the shaft be[illegible] barely 20 inches, it will be seen [illegible] motor is a wonderfully compact [illegible] engine. It is also claimed that its economy in steam is remarkable.

Another semi-rotary is the engine ascribed to Brotherhood or Colt, in which several cylinders with single-acting pistons are mounted horizontally — revolver fashion—round a central shaft carrying a rocking-disc. This disc, though free to rock in all directions, cannot rotate without the shaft, but, as the piston rods all impinge upon it in turn, a rotary motion is imparted to the disc and shaft, the former driving back each piston in the exhaust stroke as it receives the impulse from the one on the other side of the series. Such, at least, is the description I have received of the working of this motor, the accuracy of which I do not accordingly vouch for. But I should imagine that as much power was lost through friction of the numerous parts as could be gained from the rotary character of the device. Turbine rotary motors have also been proposed for automobile work, but would not answer in practice, in my opinion, because they are only efficient at a very high speed. This would not only require a high normal fuel, water, and steam consumption, which would be largely lost, as reducing gear would have to be fitted, but power would be lost both in this gearing and that of the transmission to the road-wheels.

CHAPTER VII

BOILERS AND BURNERS

WE have now to consider the various types of boilers or generators employed for the steam propulsion of road vehicles, the choice of each type, and to a certain extent its construction, being governed by several inseparable conditions. In the first place, they must be as light as possible, consistent with safety, efficiency, and durability, since they represent, in any case, so much dead weight, which the engine must propel, as well as its own weight, that of the connections and other parts—condenser, fuel or fuel-and-tank, water-and-tank—before any account is taken of the weight of the car body, wheels, and passengers. Secondly, they must be as little affected as possible by any contingencies, such as road-shocks, which must in no case hinder their efficient working. Thirdly, they must not only be able to generate steam rapidly soon after the start from a freshly lit fire or burner and cold water up to a working pressure—the "head of steam": from 150 to 250 lbs. per square inch—but must continue to maintain that pressure with economy and general all-round efficiency without interruption.

Fourthly, this generation must be effected within a small compass—the smaller the better—because great bulk of parts, quite apart from any question of weight, is out of the question on a vehicle intended for transport. And fifthly, they must be safe for comparatively inexperienced persons to handle, and easy to regulate, or at least safer and simpler than ordinary stationary locomotive or marine boilers. Nevertheless, in this last connection, the prevalent idea that because these automobile steam generators are safer they are "fool-proof," and in all cases easy to handle with economy and good results, cannot be too resolutely combated. Indeed, it is not too much to say that in scarcely a single case are they "fool-proof," and in the majority of instances they are anything but easy to handle for good results without months of experience. At all events, we find that most of the above essentials are only to be found in certain fire-tube boilers, water-tube boilers, and in the so-called "flash" boilers, or instantaneous steam generators. In reality, the majority of the last class, namely, those which generate steam instantaneously at highly heated points in a series of tube elements, to which the water is supplied, by pump-stroke, as the steam is required, are not flash boilers at all, but rather true salamandrines. The latter term is, however, inconvenient, as the well-known Ofeldt water-tube boiler, which is equally of the true water-tube type, is known as the Salamandrine.

Fire-tube boilers, which are mostly used on heavy commercial steam vehicles, have their fire-tubes or flues either horizontal or vertical. Here we have a choice of advantages offset by equal disadvantages. The former class use their heat to better advantage because it passes more slowly, but then, their length absorbs too much space in a commercial waggon or other vehicle, and if this length be reduced to convenient proportions, heating surface is correspondingly lost [illegible] hand, vertical fire-tubes, though not open to these objections, part with their heat more rapidly, do not heat so evenly as a rule, and if lengthened make the boiler rather top-heavy. Both classes, however, consist (1) of a shell, *i.e.* a cylindrical body closed at each end by plates, generally flanged and riveted to the cylinder walls, but in one or two instances made in one piece with the latter; and (2) a series of drawn steel or copper tubes—the flues—varying in number from two hundred to five hundred, which are expanded at their ends into each plate. The water, of course, circulates in the spaces between the tubes. Generally, especially in fire-tube boilers for heavy commercial vehicles, the outer shell of the boiler extends downwards to form the furnace, and the lower plate likewise extends downwards inside to form an inner shell, thus making an annular water-heating jacket around the furnace. Sometimes thicker tubes are used, here and there among the rest, to form stays between plate and plate. Again, the situation of the fire-door, through which the fuel is fed to the furnace, varies; being replaced in one instance—the Coulthard—by a large central tube passing downwards from the top of the boiler, through the water-space, to the furnace. It is said that this construction gives more equal expansion and contraction, better heating, and prevents the tubes leaking. In boilers using liquid fuel, the burner, which is almost always some variation of the Bunsen type, is placed in a pan in the furnace or fire-space, and in light vehicles close beneath the boiler.

Water-tube boilers—first invented by Pierre Ravel—are of many kinds. In all, however, the tubes contain the water, while the fire and heated gases circulate in the spaces around them. The tubes are arranged in a great variety of ways. In the Scotte boiler they are large vertical tubes of the Field type (not unlike a nest of test-tubes) suspended from the upper plate of a water-jacketed inner shell, the flue passing through the centre of the steam-space above; or, as in the De Dion-Bouton, arranged in coils to an outer water-jacket, connected with a central double-shell by some scores of short diagonal tubes, the flue being central as before. Or, again, they may be a series of diagonal tubes extending across the boiler from one side of the inner water-surrounded shell to the other (Wiedknecht). In the Savage boiler four series of tubes—nearly a hundred—extend from the top plate of a closed trough at one side of the square furnace, diagonally upwards to the other side, then backwards and upwards again to a solid-drawn steam drum situated above the trough, and connected with it by a single row of large "down-comer" tubes. Then, in the Thornycroft and some others, we have a circular arrangement of tubes more or less curved to allow for expansion and contraction, and diagonally inclined towards the centre, around the fire-space, expanded into an annular trough-like drum below, and into a smaller one above, the brake (or unevaporated) water being led down from the latter to the former by "down-comer" tubes. Again, we have boilers of the Yarrow type, the section of which is triangular, the fire-grate forming the base, two trough-like drums the lower angles, into which the sides—three or four curving layers of water-tubes to the number of several score—are expanded, their upper ends being expanded likewise into the apex, a cylindrical steam drum, from which down-comers again lead into the water-drums below.

Of this last there is one type, which has been patented by J. S. Sargeant, of Chiswick, that has latterly gained a deservedly high reputation, not only for rapid and economical evaporation, but for remarkably rapid circulation—the point in which the majority of water-tube boilers are liable to fail in unskilled hands, despite all claims to the contrary. On this account, particularly as it is now being applied to steam waggons, for which work its small bulk and light weight render it especially suitable, it deserves special description. It is true that the differences in construction between a Sargeant boiler and an ordinary Yarrow are but slight, but their effect is so great as to place the former almost in a class by itself. In the first place, the outer layer of tubes is rather more curved at the top, and all the layers enter the steam-drum on each side somewhat higher, but just below a flange or deflector which extends lengthwise on each side from end to end of the steam-drum. These deflectors separate the dry steam from the "brake-water," the former being slightly superheated, while the latter is turned downwards into a trough which is of narrower diameter than the drum. From this trough, through the ends of the drum, the down-comers lead the brake-water back into the troughs beneath. Now, as the trough is less exposed to the heat of the furnace than the drum, it serves to cool the brake-water slightly; and as the rapid steam separation by the deflectors has given it an earlier head of water than if no such separation had occurred, these two conditions create a powerful downward feed into the troughs, which again forces the water up [illegible] the tubes with such rapidity that the latter h[illegible]portunity to overheat. Thus leakage is pract[illegible] ated, the life of the tubes indefinitely lengthened, and rapid circulation and steam generation secured at all times. The shell of the Sargeant boiler consists of light plating, with sheet asbestos layers between the outer and inner plates. Paraffin, from the Sargeant patent burner, is the usual fuel.

All the above boilers, which are mostly used for the heaviest waggons, are fitted with safety-valves, steam gauges, and, in some cases, superheaters, blowers, and various appurtenances common to stationary boilers. "Flash" boilers, on the other hand, which either only contain a small quantity of pump-delivered water—in doses, so to speak—or, at least, are so supplied with water that they cannot generate more than a limited amount of steam at a time, and then no more until that has been used, naturally do not need any of these appliances. Before discussing these, however, we may note, in the Toledo boiler, a steam generator which forms a kind of link between the two systems, since, although it has an outer and inner shell comprising an annular water-space, with a steam-space above, it also has an inner tube-coil with certain of the "flash"-boiler characteristics. This consists of a series of spirally coiled tubes, each wound beehive fashion, not interconnected, but connected with the water-space at the bottom and the steam-space above. Some of the outer spirals are more diagonal—probably to increase the rapidity of the circulation—than the majority, which are mostly horizontal. The water is thus partially warmed in the shell-space, rapidly circulated and evaporated in the coils (steam also being drawn from the steam-space above into the coils), finally superheated in the inner windings, and delivered to the motor by a central pipe

passing through the top of both shells. This is generally regarded as a "safety" boiler, and is used on the well-known Toledo steam cars.

Now the conditions governing all "flash" or "semi-flash" steam generators are, firstly, that a flame merely capable of heating the tube-coils—at the steam-generation points—to a dull red is quite sufficient, not only to generate, but absolutely superheat the steam. Hence the fuel-supply must be regulated so that a certain degree of heat is not exceeded, otherwise the tube will not only be damaged, but its inner surface will refuse to be wetted, and no steam will pass. Secondly, the water must flow to these points in such regular quantities (fixed in ratio with the fuel-feed) that the tube will be maintained at the proper temperature, or else the same troubles will arise, even though the fuel-supply does not exceed the normal. Similarly these quantities must not be exceeded unless the fuel-feed is increased correspondingly, or the tube heat will fall below working temperature; such steam as is generated will be wet, or actually pass as brake water and flood the engine. Thus, whether the amount of steam generated be more or less, the *ratios* of fuel-feed and water-delivery must be constant, and correspond during all speed variations, although their *amounts* naturally vary according to the amount of steam required at any given time; these increasing or lessening according to the speed, or ceasing altogether (except for a pilot light to the burner) when the engine is stopped; but being in all cases *balanced.*

But as there is so little—almost none—of steam or water-space in reserve in all cases but one, two conclusions follow. First, that whatever variations occur in the water-delivery are immediately repeated in the steam generator—even with normal fuel-delivery and heating—and thence again in the engine. And if fuel-feed and heat be either excessive or too slight, troubles arise, as has been shown. Secondly, that this balancing of operations is extremely delicate, and can only be done by linking the water and fuel-feed in mutual control *interdependently*, or by introducing a common controlling medium, which governs both equally, but *independently* of each other. Consequently, these controls, whether mechanically or physically effected, or by a combination of both, must be automatic; and therefore introduce appliances and systems which, although essential, are more or less complicated in mechanical arrangement or detail, if not in their working. Of course, the simpler they are, the better, so long as efficiency is not lessened.

These methods of control, then, are: (*a*) by actual mechanical linking of the respective feed mechanisms; (*b*) by thermostats—devices so constituted that, by the action of the *temperature* of the superheated steam, they regulate the fuel-feed, lessening or increasing it automatically as the temperature rises or falls respectively above or below a ratio corresponding with the ratio of the water-feed; and (*c*) by valves automatically controlled in present practice by (1) water-pressure actuated by air-pressure, automatically created in a pressure tank by the force of the main water-feed with which the tank is interconnected, this opening a by-pass to a return pipe; (2) by the surplus *pressure*—if any—of the steam, which thus escapes back to the water-tank, drawing the surplus water (through an auxiliary connection) along with it; or (3) by the steam-pressure, opening a by-pass which returns the water to the tank side of the pump before it can reach the generator. Most of these systems are arranged with separate hand or foot control at the points indicated, as well as at others; and in some, safety-valves are introduced, but more in a supernumerary capacity than as the chief protective or regulating device, as in the boilers previously discussed.

Coming at length to the construction of the three best-known instantaneous steam generators—namely, the Gardner-Serpollet, Chaboche, and White—we find that the first named consists of a square asbestos-lined shell, containing a number—thirty-two in one size—of horizontal layers of drawn-steel tubing. Of this number, the upper twenty-four are wound gridiron fashion, the run of one layer being at right angles to the run of the one next it, above and below. The remaining layers are larger and thicker, and arranged in a continuous square coil at the bottom of the shell round the burners. All the gridiron layers are interconnected at their ends outside the shell by U-shaped bends, and are thus removable, these bends being also covered in. The water is driven in at the top from a pump, the mechanism of which is linked with that of the fuel-pump; that is, actuated by the same rocking lever. It is then slightly heated in the top layer, then driven right down to the square coil—the feed-water heater—the burner heat now assisting the circulation. Next, it is sent upwards through the lower gridiron layers—the steam generators—and thence outside and straight up to the second layer, and finally downwards through the middle gridiron layers—the superheaters—passing out through the central one as superheated steam into the supply-pipe and throttle to the engine. Thus its circulation is partly forced by the pump, partly led by gravity, and partly hastened by the heat of the burners. It will be noticed, too, that there is no point throughout where it can pocket to form a reserve. The effect of this will become clearer later on. On its way to the throttle the steam passes a branch pipe, through which its pressure, if in excess, relieves the water-supply through a relief valve, in the manner described in *c* (2) of the foregoing paragraph. The balance of fuel- and water-feed ratios is thus interdependently maintained, mechanically and physically, *so long as the mechanism of supply does not fail*, as this control system apparently only corrects *excesses*, but not *deficiencies*, whether caused by wear or accident to the supply mechanism of either water or fuel. Yet, obviously, any deficiencies would equally upset the balance of ratios. Both feeds are started by hand through separate connections, but there is also a semi-automatic air-pressure water-tank, which serves to start the water-feed after a halt.

In the Chaboche generator the tubes are wound helically in five separate layers, each wound in five rows, gridiron fashion, these rows being alternately spiral and convoluted—the latter like a continuous figure 8, so to speak. The run of each grid crosses that of the one beneath at right angles as before, an arrangement facilitated by the above method of coiling the tubing. The water is driven by pump-stroke, past an automatic regulator valve—which is actuated as explained in *c* (1)—on through a storage coil to the lowest grid—the feed-water heater; thence to the top grid, which generates the steam, and downwards through the remaining three superheating girds, finally passing out as superheated steam. It then passes through a thermostatic portion of the supply-pipe, which, by expansion and contraction, controls the fuel-feed (this portion of course being fortified by a surrounding pipe) onwards to the safety-valve, through which it passes to the engine; from that to the condenser, and lastly, back to the storage tank. The storage coil above mentioned is, however, merely for heat storage, in case the steam-pressure be in excess and temporarily force the water back through it and the automatic valve into the by-pass; but is in no sense a feed-water reserve, as it forms part of the direct channel of the water-feed to the generator. Neither is the pressure tank, previously mentioned in *c* (1); as the water only leaves it when the pressure of the main water-feed is in excess, and then only to open the by-pass, returning the latter to the tank. Here, again, we see that the balance of ratios is interdependently controlled, but almost entirely physically, and with much greater complication in detail. Any deficiency in fuel-feed arising from failure of the supply mechanism is apparently not provided for.

In the White generator, however, we have an entirely different, practically unique system—in construction, steam generation, and control; one, moreover, if I may be allowed the remark, which represents control in its simplest and most efficient expression. It consists of a cylindrical, asbestos-lined iron shell, in which twelve horizontal, helically coiled tube layers are superimposed one above the other, and held in place by the arms of U-shaped distance-pieces. All these are interconnected each with the next above and below it; but the manner in which this is done constitutes at once the chief feature of the construction and the secret of its remarkable efficiency. Each connection turns upwards to the level of the top of the coil before turning downwards to connect with the coil layer next beneath it. Thus the water, driven by the pump-stroke, enters the inmost winding of the top coil layer, and circulates outward to the outmost winding; then rises upwards and across the coil to the centre again, and downwards into the inside winding of the second coil. Circulating outwards as before, it rises again with the outside winding to the top of the first coil, across it to the centre again, and down into the third layer, and continues in the same manner. This perpetual rising to the top from the outside, and crossing it before entering the coil beneath, continues right to the lowest layer, the outmost winding of which is led upwards half-way before bending downwards, syphon fashion, into the bronze casting enclosing the thermostat, from which a straight piece of piping runs up the side of the generator, and outwards again in a large elbow-joint to the engine connection. The crossover connection between each element and the next is made throughout by short lengths of tubing, screwed right and left into elbow-joints on the upturned ends of the elements.

Thus it is obvious that each coil layer can only be filled from the overflow from the one above it. The water, therefore, being led in at the top, cannot pass downwards by gravity, as in other generators, but is entirely dependent on the action of the pump. And even the latter cannot throw it into the first coil, if the steam-pressure exceed the normal, as a diaphragm valve in connection with the steam-supply pipe cuts out the water-feed into a by-pass, as in *c* (3). Thus driven in a constant ratio by the pump—or by the starting hand-pump which enters on the *further* side of the above diaphragm—the water enters the top coil and flows through the next two or three—the feed-water heaters, in the manner above described : is turned into steam in the four middle layers, at some point depending on the amount of steam being used, and superheated in the lower-most layers, passing through the thermostat casting—its temperature as steam regulating the fuel-feed, as in the method described on page 117 (*b*)—and finally passes upwards through a throttle to the engine and thence to the condenser.

The balance of ratios is thus controlled *independently* by the steam—by temperature in one case and pressure in the other ; and in both cases by physical means with no mechanical complication whatever. Again, it will be seen that, owing to the special method of interconnection of the coil layers, there is always a reserve of water in the upper coils—equal to about a third of the entire capacity of the generator—to enable steam to be raised on restarting, as soon as the burner is turned on. In fact, this reserve constitutes one of the only *self-induced* automatic self-starters in existence, owing, in my opinion, to a point which seems to have been neglected in most descriptions of the White generator. This is, that the upturning of each coil-end with its cross-connection and downward lead into the coil-layer beneath appears to act as a syphon to draw the water into the latter as soon as circulation has been induced by heat from below. This action upon the water reserve in the upper coils would seem to start from the lowest coil-layer, thus generating sufficient steam to start the engine, and with it the pump, Apparently it is owing to this physical peculiarity that we derive the fact that the steam can be generated and the car run until the last drop of water in the coils has been evaporated—as the makers claim—even after the pump, having emptied the tank, has ceased to throw. And with the heat of the steam thus abnormally raised at the last few steam generations, it will be seen that the thermostat would act rapidly to reduce the fuel-feed, which would finally cease with the last of the steam; as the engine and pump would stop. Thus no damage to the tubes, even the lowest layer, could occur, as the ratios of fuel- and water-supply would be balanced until the last moment, despite the rapid reduction of amounts.

Having discussed the above three types of instantaneous steam generators to illustrate the principles of control, we may close the present chapter with a brief description of the two principal types of liquid fuel burner. These, as has been said, are Bunsen burners, differing merely in the methods of inducing, vaporising, and regulating the fuel, but chiefly in the system of induction. They may therefore be divided into two classes—air-inducing and steam-inducing burners. In the former, which are by far the most numerous, the differences lie in the mechanical construction by which the following results are produced, namely: (1) Vaporisation of the liquid fuel supplied under pressure in a coil or chamber, which is heated at the start by temporary auxiliary means, such as the burning of a little spirit in a pan, oil-soaked cotton-waste, a lighted wick, or a blow-lamp; and (2) the automatic induction of a strong current of air sufficient to maintain combustion. This induction is partly due to mechanical means, such as the form of the draught-chamber or induction-pipe, a blower-shutter or valve also increasing or reducing the draught. But this is effected for the most part physically, being set up in the first place by the pressure at which the vaporised fuel is supplied, and secondly, by the rapid combustion of the latter, the air-draught and vapour-pressure, so to speak, reacting upon one another to increase the size of the flame. Mechanical means have therefore to be provided to regulate the volume of the fuel-supply in any case, and in some instances—such as the Clarkson-Capel, perhaps the best-known and most powerful—that of the air also, the controlling mechanism being linked up to a thermostat or other device for automatic regulation.

These air-inducing burners may further be subdivided into (*a*) pan or multiple-jet burners, with vaporisation from a common chamber; (*b*) multiple-jet burners to which the fuel passes through a vaporising coil; (*c*) single-jet burners with either chamber or coil vaporisation; and (*d*) single-jet burners arranged in multiple, each with its vaporising coil connected up to a common fuel-supply. The first variety typically consists of a pan-shaped receptacle, containing either a row of jet-pipes—similar to those of a gas stove—or a coil-like chamber with jets or saw-cuts, or radiating jet-arms, or a chamber-like section of a fire-tube boiler; all being fed from a common vaporising chamber, into which the fuel is injected under pressure, and which is maintained automatically in a heated condition by the burner flame. In these the air enters freely through holes between the jet-pipes or coil-ridges. The White, Prescott, Toledo, Weston, Simpson (33, 10073 and 16440, 1901), and other steam-car burners are of this type.

Multiple vaporising-coil burners, on the other hand, consist of single jets arranged as separate burners, a series of which are fed from a common vapour chamber supplied by a vaporising coil or grid, the convolutions of which wind among the different jets, and being held in the flame of each, are kept at the proper heat. Such is the Gardner-Serpollet burner, to which the air enters through a draught chamber, passing upwards through little chimneys into the vapour chamber. Single-jet burners, again, are fed by a vaporising coil, helically and spirally wound inside or outside a bell-shaped or coned chamber, the mouth of which serves as a deflector for the flame from the jet in the centre, while the air and vaporised fuel enter the jet at its base from the mixing chamber or the air-induction tube. The jet itself may be annular, like the Clarkson-Capel or Johnston burner-jet, or have radiating arms (Longuemare), or consist of a dome (Blaxton)—these three last being freely perforated—or, again, as in the " Lifu," the single-nozzle jet may be served by a vaporising chamber in which the fuel is driven round a series of corridors or baffles. The Chaboche burner is a typical example of single jets connected in multiple, each with its own coil vaporiser, fed by a common supply-pipe.

In the other class—steam-inducing burners—we note that the fuel is not necessarily supplied under pressure, but generally—carburettor fashion—by gravity from a float-feed chamber and forced out of the nozzle of a single-jet burner by the pressure of a jet of steam. In order to start these, very little steam is needed, and this is supplied from a small auxiliary boiler through a two-way cock, which, as soon as there is a sufficient head of dry steam in the working boiler, cuts off the steam-supply from the starter. Most of these, however, are troublesome and extravagant in practice, as the fuel is *driven* out by the steam; and the combustion depending solely on a very high *and constant* degree of steam-pressure, the slightest variation in the latter causes a break in the fuel-supply, which extinguishes the flame; also the jet is liable to choke. One notable exception, however, exists in the Hydroleum patent burner, in which the steam-jet has the lead, and *draws* the fuel with it through the nozzle. The fuel is then enclosed in a jacket of dry steam, and, it is said, serves to split the latter into its elements during combustion, the oxygen set free assisting the combustion of the fuel, and the hydrogen increasing it.

Be this as it may, it is certain that the crudest liquid fuels (and oils, such as green gasworks oil, which have hitherto been regarded almost as refuse by-products, to be had for the asking) can be burnt with a perfectly clean combustion. The use of such oils, nevertheless, is out of the question in burners with a driving steam-jet. Furthermore, owing to the *drawing* action of the steam-jet of the Hydroleum burner, a great variation of steam-pressure is permissible, which enables the flame to be reduced or increased throughout an extensive range without being extinguished. The above-mentioned combination takes place in the open end of a rectangular fire-clay and asbestos-lined chamber, into which the nozzle projects, the flame being then deflected upwards into the circular fire-box of the same material, which constitutes the boiler furnace.

All steam outfits include a condenser, unless the exhaust is passed direct into the surrounding air. This practice is permissible on the lightest cars, on account of the small volume of the exhaust, but on larger ones it is obvious that some such device is necessary; for, as its name implies, it cools the exhaust into water, which can be used over again. Commonly, a condenser differs but little structurally from the radiator of an internal-combustion motor cooling system; consisting mostly of a series of tubes with radiating gills or wire coils. These tubes, similarly, are either in one continuous coil or are expanded into a tank-frame at their ends. Their metal, however, is usually thinner, and of some freely conductive kind, such as copper or zinc, so as to hasten cooling. It may be thinner, of course, than in the radiator first mentioned, because the pressure is much slighter than in the latter. Sometimes the condenser is a large tubular casting, or, again, may be a simple air-cooled tank. On most steam cars, however, it either leads direct into the water-supply tank, or else is emptied by pump into the latter; the water being thus used over and over again, except for the small percentage which escapes or is blown off at the safety-valve. Again, the water-tank itself may be used to condense the exhaust steam.

CHAPTER VIII

ELECTRIC MOTORS AND DYNAMOS

THIRD on the list of motors employed for automobiles, by reason of their more restricted sphere of usefulness, though their final efficiency, reckoning from one end of the power-scale to the other, is about the same as that of steam, we must place electric motors.

Numerous scientists, before and since the time of the great Faraday, have been credited with the invention of the electric motor, and its converse, the dynamo; but so far as can be learnt, the first one was constructed in 1838 by Ivan Jacobi, a Russian scientist, who employed it to propel a small launch on the Neva. His type is, however, still more obscure; but, being merely interesting historically, need not be discussed here. Modern electric motors, as used for the automobile, consist of five essential parts, namely, (1) one or more field-magnets, consisting (*a*) of field coils; (*b*) field-winding —insulated copper wire, of various degrees of thickness, in single or separate windings, or both combined; (*c*) pole-pieces; and (*d*) the yoke. This last is of the same metal as the pole-pieces, and generally as the cores also, and serves to unite them. In practice, in the type of motor most usual on electric vehicles, each half of the shell of the motor is cast uniform with one

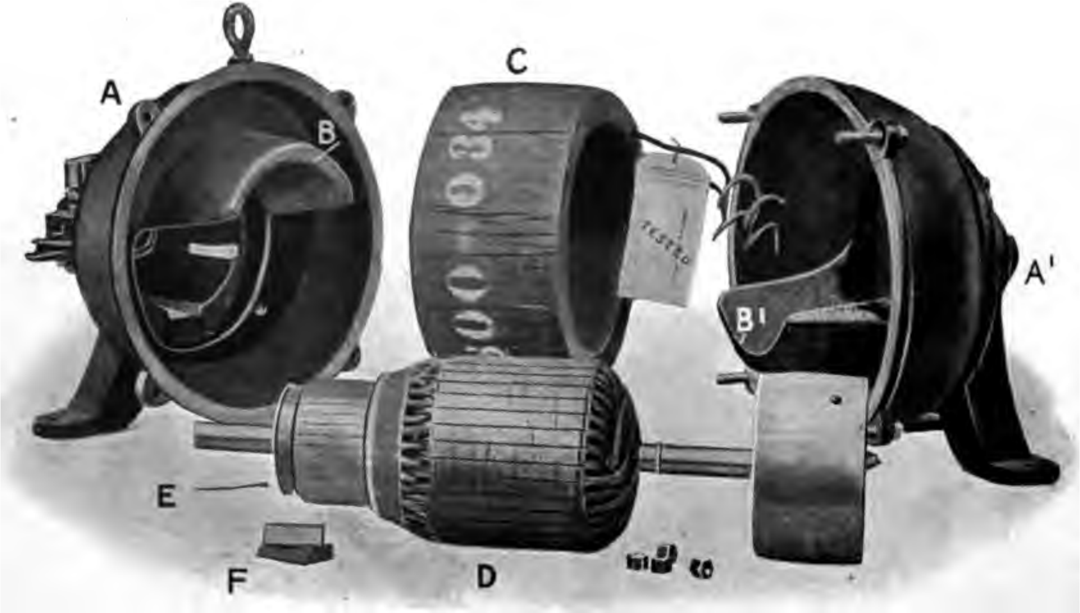


FIG. 13
AN ELECTRIC MOTOR: SHOWING PARTS

of the pole-pieces, to form half the yoke; the field-core winding, as a separate mass, fitting closely over the pole-pieces when both halves of the shell are brought together. The accompanying illustration shows a Lundell motor, one of the bi-polar type, dismounted.

The remaining essentials, as will be gathered from the illustration, are: (2) an armature on a shaft, mounted in suitable bearings, as shown above; upon which latter is also (3) the commutator—different in construction, but similar in function, to the one already discussed; (4) one, and in some cases two, sets of secondary cells, arranged in four groups for convenience in effecting speed-changes, to give out the current; and, lastly, (5) a set of thicker insulated current wires—connected with the battery of cells on the one hand, and with the field-magnets and the armature on the other—through suitably mounted rods of carbon or pieces of strip copper, the brushes. These last will be seen at M, in the assembled motor in Fig. 14, part of the casing having been drawn aside; and singly, as well as the field-coil, below (Fig. 15); as well as Z 1, 2, 3, the connecting cables. These cables or current wires and their brushes conduct the current from the accumulators to the field-coil or magnets, and, through the commutator, to and from the armature and back, through the controller, to the accumulators to complete the circuit; or in another arrangement, to both at once through the brushes on the commutator. Strictly speaking, there are four types of electric motors: separately excited, shunt-wound, series-wound, and compound; the last being practically a combination of the second and third types.

But before describing the manner in which all these parts are combined, it will be necessary in this case to examine the *construction* as well as the constitution of each part, in order to understand its relation with the others, because the action of an electric motor is so much more physical than that of an internal-combustion or steam motor, in both of which the mechanical element is the more obvious. It must first be premised, in regard to the field-magnet or coil, that if an insulated wire be wound round the arms of a D or horseshoe-shaped casting of soft iron or mild steel—the core—so that the windings begin at the end of one arm and work upwards, leaving that arm at the top and crossing over to the other, then beginning at the underside of the latter and continuing downwards to its other end, the *mass* of perhaps the simplest form of bi-polar field-magnet will be made. Similarly a ring of soft iron or steel may be continuously wound—as in the type of field-coil previously illustrated—to constitute such a mass, the pole-pieces, in one, two, or more pairs being formed as part of the yoke-casting. Again, one or more pairs of castings—of suitable shape to take windings—may be arranged around a circular yoke, with their free ends or faces opposite each other diametrically to form opposite pole-pieces, and, when wound continuously, will also make up the mass of a field-magnet. But any such a mass will not actually become a field-magnet until—and only for so long as—an electric current is passed through its windings. This being done, the free metallic faces of the pole-pieces, oppositely exposed to each other, will form strong magnetic positive and negative (N. and S.) poles, the space between them constituting the magnetic field.

Turning next to the construction of an armature of the drum type—which in one or other of its makes,

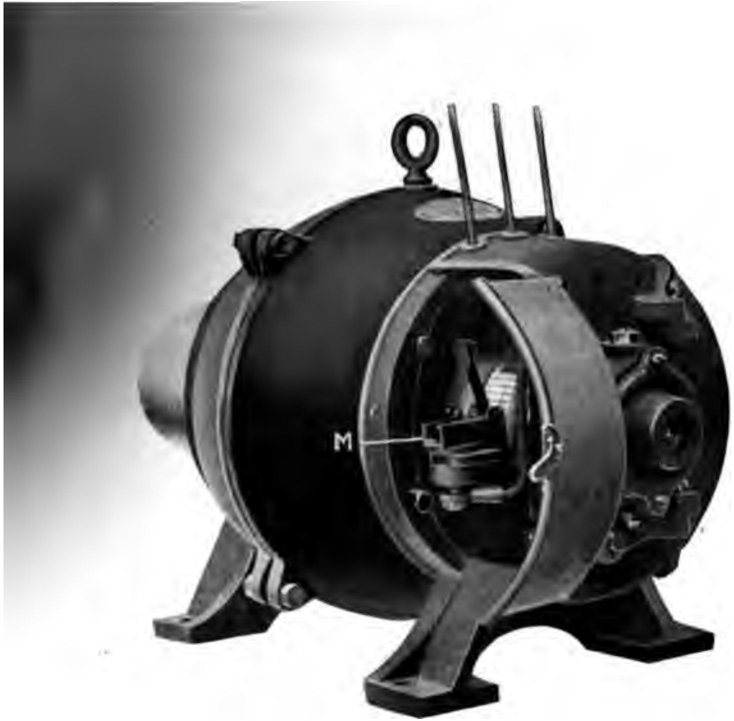


FIG. 14
AN ELECTRIC MOTOR—ASSEMBLED

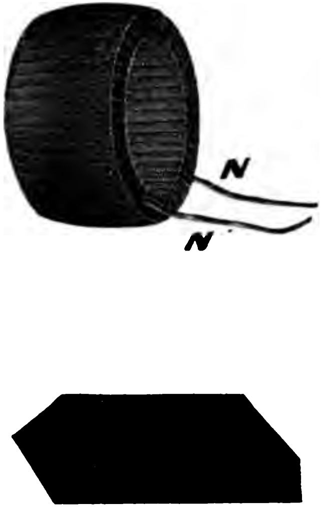


FIG. 15
THE FIELD COIL

varying chiefly in the method of winding, is almost universally employed in electric motors for vehicles—we note that it also consists of two main elements, the core and the winding; to which may be added the commutator, with which the armature is integrally connected. The core, then, is made up of a number of flat annular discs, which must be made of the softest iron in order to give the armature the greatest power of absorbing magnetism. They must also be insulated lightly from one another, so as to resist the formation of what are known as eddy currents. After having deep grooves or slots cut in their outer edges (forming teeth and spaces) they are assembled and clamped together by bolts so as to form a cylindrical mass, the teeth and spaces of which correspond throughout its length to form continuous alternate grooves and ridges, running lengthwise from end to end of the mass. The core is next keyed on a shaft mounted in bearings (or in some cases held at each end by a dished wheel-like body called a spider, duly mounted on a shaft) so that the core-mass may be freely rotated.

In the above-mentioned grooves a continuous length of insulated wire is wound lengthwise over the surface of the core, each series of windings being interconnected to those on either side of it by attachment to the vertical arm of one of an equal number of L shaped copper, gunmetal, or phosphor-bronze segments. These metals are chosen because of their high conductivity, or low resistance to the passage of an electric current. The horizontal arms of these segments are embedded side by side in a drum or cylinder of vulcanite, mica, or similar non-conducting material also keyed to the core-shaft; each segment being thus separated from the next one by a ridge of insulating material. The whole thus forms a drum of flat metal plates (the other arms of which are connected solidly with their respective pairs of armature windings) and presents a free surface for the brushes previously mentioned, which convey the current to the armature. Such, then, is the commutator, the function of which will become apparent in the following paragraphs.

To this, then, the current wires *from* the accumulators and *to* the field-magnets are connected by the slipping or face-contact of the brushes, which are supported by special holders in such a way that their ends shall make as large a contact as possible with the plates of the commutator, namely, at an angle of some 45° from the vertical. They are also held above and below the commutator parallel to each other, but with their contact-faces also out of the vertical. Being thus in perpetual slipping contact with the commutator, they serve to feed the current into the latter, thence into the armature, out of that again, and back into the circuit. Now when the armature, with its commutator and shaft, is mounted at right angles to the poles of the field-magnet lengthwise—that is to say, with its sides lying between the faces of the pole-pieces—so that it is left just free to rotate, both these parts being maintained in permanent relation to each other, the whole combination is ready to become a motor.

Then, if the current be thus conducted from the accumulators into the armature at the same time that it is turning the field-core and winding into a field-magnet, two double poles, N. and S., will be created in the former at right angles to the lines of magnetic attraction between the poles of the latter. Actually this occurs in line with those stationary points at which the current enters and leaves, *i.e.* at the brushes. The result, at any rate, is that strong attraction is set up between opposite poles of both armature and field-magnet. This is the magnetic drag, the further consequence of which is that rotary motion is at once imparted to the armature. But, obviously, the nearer these opposite poles approach one another, the easier it will be found for the current to pass, and the nearer the armature poles are to the vertical, the more difficult.

Consequently it follows that the strength and direction of the current will constantly vary, first in one direction and then in the opposite one, in alternating currents. Here, however, is where the function of the commutator comes in; for, the brushes being fixed at the neutral points (*i.e.* those points in the armature cycle at which the currents move in one direction), each segment of the commutator as it revolves beneath the brush gives up its current in one direction also. And the induced current being thus perpetually compelled to flow in that direction, while the same attraction is continuously set up between the opposite poles of field-magnet and armature, a continuous rotary motion is maintained by (and for) the latter, and consequently for its commutator and the shaft upon which both are mounted. This shaft, of course, also has a sprocket, pulley, pinion —or any suitable means of transmitting the mechanical power thus obtained—keyed upon it.

It is, then, this perpetual rotary effort, called *torque*, upon which all electric motors depend for their mechanical power. Yet it will be clear from the foregoing paragraphs that it would have been almost impossible for the reader to arrive at this conclusion in a rationa fashion, without detailed explanation of the constitution of these motors at greater length than has been necessary in the case of those previously mentioned. We have still, nevertheless, to discuss the nature of the accumulator cells already mentioned. These are secondary batteries of much the same generic type as those used for current storage in electric lighting, but have been so far modified as to give them an output capacity three or four times greater for their weight, and to enable them to stand over-discharge and rough travel. These modifications will be better understood in subsequent paragraphs. Suffice it for the moment to say that an accumulator consists of a set of cell-elements, varying in number (according to the maker) from forty to forty-four. This number not only enables them to be charged from the ordinary supply-stations, but also, by dividing the accumulator into four batteries of equal strength, to make contact for the various speed-changes. Each cell-element, again, contains a number—which varies much more widely—of positive and negative plates. This last, it might be thought, would be an even number, but in practice there is generally an extra negative plate. The reason for this is twofold. In the first place, the current is given off by the energy developed by the chemical reaction of the electrolyte—the liquid reagent in the cell—upon the plates; and secondly, because the positive plate contains the substance acted upon, the attack of the electrolyte upon it is greater, and would warp or "buckle" it, unless protected by the extra negative plate.

As to the plates or electrodes themselves, in theory any combination of two different metals of sufficient conductivity or low resistance, so long as it gives out

an inappreciable amount of volatile products during charge or discharge, may form an element in an accumulator, together with a suitable electrolyte. Hence the investigation on the part of scientists in order to produce one that, while giving an equal or greater voltage, shall be lighter than any of the three combinations—lead-and-lead, lead-and-zinc, or zinc-and-copper—which alone have given satisfactory results hitherto. Now the second of these is lighter of course than the first, and gives as much as 2·4 volts, but is so difficult to charge as to be out of the question for traction purposes. On the other hand, the zinc-and-copper one—in which caustic potash, 20 % solution, is the electrolyte—though obviously lightest of all per pair of plates—and not difficult to charge, only gives ·8 volt current. We have thus had to depend upon the lead-and-lead combination, all elements of the kind being of the type devised by Planté in 1873, or of that introduced eight years later by Faure. The former are now practically discarded—though some authorities consider that better results are obtained with a Planté positive and Faure negative—and the latter have been reduced in weight and generally improved out of all knowledge.

Nowadays, however, all plates of the Faure type consist of grids—not unlike a honeycomb—each frame-like cellule acting as a pocket into which is pressed a paste formed of lead oxide and some substance that increases the porosity and cohesiveness of the paste. It is at this point that mention may be made of the manner in which improvement has been achieved. In the first place, the shape of the pockets has improved, and their size, together with the thickness of the plates, has been considerably reduced, so as to reduce weight and allow the paste a greater degree of uniform expansion with less risk of the pellets dropping out during discharge. Then the electrolyte—a solution of sulphuric acid in this case—has been increased in density, and therefore strength, and the composition of the paste itself materially improved. The result of all this is that the volume and weight of the whole element have been decreased and its output increased.

Practically, all elements of the Faure lead-and-lead type consist of a positive plate of antimony-lead and a soft-lead negative plate, connection between them being made by cross-pieces of lead or an alloy. They are, however, separated as a rule by thin sheets of vulcanite, freely perforated to oppose the minimum of resistance to the passage of the current between plate and plate. Each plate, as a rule, has a neck formed at one end of its upper edge for connecting with the next one, the other plate of each pair having a similar neck on the opposite end. Connection is thus made in parallel—all the N. and all the S. poles—by a bridge of metal at either side of the element. Short circuit—*i.e.* failure of current passage through actual contact of the masses acted upon—is avoided by placing indiarubber rings, or a freely perforated ebonite plate, between each positive and its negative, the perforations offering no resistance, of course, to the current passage. The mass of the plates is also held together by rubber bands and supported on rests or forks at the bottom of the sealed vulcanite tank which contains it, as well as the electrolyte. The whole thus forms a cell, which is connected—through its contacts at opposite ends of each bridge—to the next, in series (N. and S. to S. and N. respectively). Now the effect of charging being to form peroxide of lead on the positive and pure lead on the negative, it follows that lead sulphate—the original composition prior to charging—will again be formed as the cell is gradually discharged under the action of the electrolyte, the energy stored during charging being given off as current. Recharging restores the *status quo ante.*

For some considerable time until its recent appearance premature reports were circulated concerning the new Edison accumulator. However, its merits compared with others need not at present be discussed, although it is improbable that so far as lightness is concerned per current output, any advance has been made. It has, however, been favourably tested in this country, and as a departure is at least worthy of a brief description. It consists of fourteen positive and the same number of negative plates of nickel-steel, $\frac{3}{16}$ in. thick, each forming a grid with twenty-four pockets, the frames of which are pierced with fine holes to allow of the free passage of the electrolyte—20 % caustic potash—to the active material. These pockets contain briquettes (forced in under pressure) of finely divided iron and graphite in the positive plate, nickel peroxide and graphite in the negative, the whole being contained in a nickel-steel box with a soldered cover. It is said that this new accumulator is not injured by overcharging, the roughest usage or travel, or a high rate of discharge, and that it has given excellent results in ordinary working. Its electrical efficiency, nevertheless, would suffer under such conditions. The weight is said to be 53 lbs. odd per electrical horse-power [illegible]

Having thus discussed at necessary length [illegible] stituen[illegible] electric motor, [illegible] the ch[illegible] difference [illegible] four varieties—*i.e.* separately excited, series-wound, shunt-wound, and compound—and to consider the apparatus employed for their control as briefly as may be. The first variety, as may be gathered from the name, are those in which the field-magnet and armature are supplied with current from separate sources. These are not, however, much used for automobile work. Series-wound motors are those in which the two poles of the magnet are wound with a heavy, low-resistance wire, one terminal, the S. pole, of which is connected to one of the brushes, while the other, N., is connected to the outside circuit, at the S. pole of the accumulator, the current passing from the N. pole of the latter to the armature through the other brush. It thus goes through the field-winding before or after passing through the armature, in series. In shunt-wound motors, on the other hand, the winding of the field-cores consists of a much greater number of turns of thinner wire (weighing, of course, the same as the series-winding), but of greater resistance on account of its length and thinness. The terminals of this high-resistance winding are connected with the brushes which supply the armature with current from the outside circuit, in parallel with the latter.

It will be seen that in this way the current is shunted into the armature windings—in which the resistance is less than in the high-tension field-windings—in a greater amount than can get through the latter owing to its higher resistance. Thus the field excited is weaker, and the armature cannot pick up its torque so rapidly. But when once it has done so, it tends to rotate at a constant speed so long as the current-pressure remains constant, whether the load-resistance

be increased or not. Consequently, should such an increase occur, as at starting, or during an ascent, it overheats, and unless relieved by the reduction of the overload, or by grouping the batteries in parallel to reduce the current-pressure, will speedily deteriorate. The series-wound motor, on the other hand, as we have seen, has its field excited first; which is therefore stronger and enables the armature to pick up its torque quicker. But because the latter is the subordinate, so to speak, in this system, its torque naturally decreases or increases with the load-resistance; although capable of a better effort at the start than the shunt-wound arrangement. Thus we see that, except upon level roads, both have their disadvantages, which are not altogether overcome—except by sacrificing flexibility—by the different controller groupings.

But in the compound-wound motor, on the other hand, we find the characteristic advantages of both combined; for the field-magnets are double-wound, first with a thicker series-winding, and then with a thinner shunt one. Or in multipolar motors, the same result is achieved by winding the cores alternately series and shunt fashion. The connections to the brushes and the outside circuit are made in series to the thicker series-winding and in parallel—thus avoiding the use of a double set of brushes—to the shunt-winding. Consequently, by coupling these windings at the start—through the controller—in series, we enable the armature to pick up its torque quicker, because of the stronger field created; and by afterwards coupling them in parallel to maintain it or increase it: that is, with the N. and S. terminals of both making the same contact on the controller, the function and construction of which will be explained presently. As has been said, in some multipolar motors the windings in each pair are different; that is, with a series-winding opposite a shunt one, as in the Krieger motor. But we shall also note that in the eight-pole motor (Mildé) the windings are placed four on either side of a central plummer-block; so that each series-winding is next a shunt-wound one, pairs with a shunt-winding opposite, and has another on each side; and *vice versâ*.

One four-pole motor which is worthy of particular mention, not only on account of the uncommonly light weight claimed for it—31⅔ lbs. per b.h.p. only, as against an average in others of about 100 lbs. or more—but also on account of its peculiar construction, is the Joel "Sine" motor. In this a single sinuous-shaped—whence the name—double-wound coil—originally wound as a ring, and then pressed so that it forms an oval on one side crossing a similar oval on the other—magnetises four interspaced poles. These poles are formed, each pair as part of one half of the motor-shell, and project into the other half between the sides of the poles formed in the latter. The efficiency of this motor is said to be as high as 87·5 %, so the accumulator weight is not likely to be disproportionate. Nevertheless, a motor, light for its electrical horse-power hour in itself, may require such compensation, since the only way to make a light motor powerful is to rotate its armature windings at a high speed. This means extra current expenditure, other things being equal, and reducing gear which loses much of the power that has been gained. Therefore slow angular speed is desirable, made up for by higher tangential speed in the armature, derived from an increase in its diameter,

which again increases weight. This may explain the reason why, in some motors, the armature takes the form of a ring, rotating outside the field-poles. It is, however, difficult to strike the threefold balance of light construction, and power, with current economy, or to get the two latter and yet materially reduce weight.

The controller above-mentioned is a device which has three familiar and functionally appropriate analogies, despite its dissimilarity in form. They are: first, to the change-speed gearing of an internal-combustion motor; secondly, to the throttle or the link-motion of a steam engine; and thirdly, to the barrel of a musical-box or street-organ. It consists, elementarily, of a cylinder made of some non-conducting material, mounted lengthwise on a lever-controlled shaft above a board on which a set of stationary springs—the contacts—is mounted. Along this cylinder plates of metal—a series of blades in some cases—are arranged in different lengths, or groups, so as to give a wide range of connections with the contacts, some of which are connected with the terminals of the four cell-groups in the accumulator, while the others are connected, as we have seen, with the windings of the field-magnets; in all cases by conducting cables. Where two motors are used there are a double set of contacts and plate- or blade-groups, so that the motors may be connected in series or parallel, or the four cell-groups; or the one in series and the other in parallel, or *vice versâ*. These contacts in all cases thus complete the circuit, as they are made in various groupings—much as the key-levers of a barrel-organ make contact with the spines of the barrel to vary the noise—except, of course, that the former are stationary for the time [illegible] the latter merely momentary. Obviously, therefore, every shift of the controller engages a new plate, or set of plates or blades, with a different set of contacts, thus making a fresh combination of the batteries and motors, either for starting and going ahead, or giving any one of three or four speeds—or further variation of these—or for reversing.

"But," I hear my wearied reader exclaim, "there appears to be only a certain amount of current available from the accumulators, which is supposed to be leaving them at a constant rate. How, then, can all these variations be effected by the controller to make its change-speed-gear analogy apparent?" This may be answered by stating that the speed is reduced or increased by taking the *maximum effective flow of current as giving the maximum speed, and by introducing, through the action of the controller, various degrees of resistance in the circuit.* This will become clearer when certain further facts have been grasped.

(1) When an armature revolves, because its windings cut through the magnetic lines of force, produced between the field-poles when a field is created, an element comes into play called *counter-electro-motive-force* (C.E.M.F). Why? Because the more rapid the flow, the more rapidly the armature revolves; also the stronger is the field created, otherwise, as we know, this increase of armature speed could not occur. But the stronger the field, the *greater the number* of lines of magnetic force produced. Consequently it becomes so much the more difficult for the armature windings to cut through them. This increase of difficulty creates the C.E.M.F. which thus renders the current-pressure non-effective, consequently reducing the torque

(2) Now, if we connect a number of cells, or batteries, in series, that is to say, the N. and S. poles of the one to the S. and N. poles of the other, leaving a free positive pole at one end, and similarly a free negative pole at the other, ready to be connected to the motor, or each other, or to any link completing the circuit, the whole series will give a voltage equal to that of all its units added together. Again, why? Because nothing has been introduced to the circuit to prevent the current taking the shortest path to complete its circuit throughout the series, as it always will, if it can. Thus if we connect four ten-volt generators in series, we shall get a pressure of forty volts or so.

(3) But if we connect them in *parallel* (= multiple), *i.e.* by two main conducting wires, one connecting all the N. poles and the other the S. poles, we shall only get a pressure equal to that of one of the four, namely, ten volts. Again, why? Because this wiring has, by increasing the length of the path fourfold, reduced the number of direct circuits between S. and N. throughout to a quarter, and the resistance to the current flow is increased thus fourfold. It is the same with motors, which, (4) if connected in series, will oppose less resistance to a current-passage than if in parallel. But, creating a stronger field, they will develop more C.E.M.F. for the armature, so to speak, to fight against. On the contrary, (5) motors connected in parallel, opposing more resistance and creating a weaker field, cut down the C.E.M.F.

Clearly, therefore, we can obtain several speed variations by the manner in which we connect the motors with the four generators, alone. Now if both motors and batteries are in series, *because of the stronger field* *created*, the C.E.M.F. will cut down the power of the motors practically to one-half. Yet if we connect both batteries and motors in parallel, we shall only get one-quarter the power speed, or torque, out of the motors, because although the C.E.M.F. has been cut down to a quarter in the latter, so has the current-pressure in the former. But if, on the contrary, we connect the batteries in series and the motors in parallel, the former will be able to exert their greatest pressure—*i.e.* give all their available current to the latter, because the C.E.M.F. *will have been cut down to that created in one motor*, thus enabling these to give their maximum torque, *i.e.* speed. Our cells, we shall remember, are mounted serially in four sets or units, varying in the number of elements according to the maker, each set of elements being connected, as we have seen, in parallel to prevent them discharging as rapidly as would be the case were they in series, and giving ten volts or a little more per unit on that arrangement. Clearly, then, if their eight terminals and those of the motors be brought up to the spring-board of the controller, the various plates or blade series will give the desired groupings for the different speeds, and the reverse by turning the current in the reverse way.

We have thus seen, with regard to torque, that its strength depends chiefly upon that of the polar attraction previously mentioned; which in turn depends upon the current from the batteries and the manner in which it is used, as well as upon the number of windings on the armature. For without the latter the current could not pass to the same amount, just as the same head of water—which corresponds in this connection to voltage or current pressure—cannot pass so speedily through a small pipe as a large one, or through one pipe as rapidly as through two of the same size. But if we increase these windings—as we must to get our power—we increase the *weight of the machine.* The same argument applies to the thickness of the conducting cables between all terminals. Consequently, as has been already stated, an electric motor of even moderate horse-power is necessarily large and heavy, the average weight being well over 100 lbs. per electrical horse-power. Beyond this, again, the weight of the accumulators amounts as a rule to over one hundredweight and a half for each designed electrical horse-power hour, thus bringing the whole device to more than 280 lbs.; which weight its torque has to overcome, as well as the dead mass of the vehicle, to say nothing of that of the passengers. And this enormous total weight, as compared with that of an internal-combustion motor and its car, power for power, not only decreases the speed when most required, but adds cent. per cent. to the cost of the tyre maintenance. For this reason we note that the tyres of electric vehicles almost invariably have armoured treads.

These circumstances naturally handicap the electric motor as compared with others, and go far to offset its advantages, such as smoothness and freedom from vibration in running, greater flexibility and high working efficiency, *from current output to work output.* Yet it must not be forgotten that its real efficiency scale—between current *input* and work output on the wheel tyre—begins in the furnace of the steam plant which drives the generators at the charging station. Of course, where water-power is available, we have the cost of the power practically reduced to its fraction of the interest and profit on the cost of the generating plant, its upkeep, and the wages of the employés; so there the electric motor scores commercially over all others. But whether this condition exists or not, we cannot get away from the perpetual necessity of a fresh current-supply for the discharged accumulators, *which can only be obtained at a charging station.* And as such establishments are not common objects of village—or even provincial town—life, it follows that the further a car is enabled to run, by means of powerful accumulators, the further it travels away from a charging station; thus increasing the risk on every outward mile of being stranded helpless by the roadside—that is, unless its circuit is restricted to routes carefully thought out beforehand.

Consequently its real travel, before such restriction or risk begins, is, at best, half its nominal travel. The efficiency scale of the internal-combustion or steam motor, on the contrary, begins in the carburettor or fuel-tank respectively, ending in the work done on the wheel tyres; and restriction of travel on account of inability to obtain fresh supplies of the power-producing element is practically negligeable; since petrol or, failing that, alcohol in some form, or heavy oil, to say nothing of water, coke, or coal, can be obtained anywhere. Furthermore, the ratio of power to weight is several hundreds per cent. more elastic. To correct these disadvantages in the electric motor as much as possible, then, what may be called a fourth type of motor has been devised.

This is the compound motor, that is, the combination of an internal-combustion and an electric motor. There are several varieties of these, and three main types; but all depend for their working upon the well-known

fact that an *electric motor becomes a dynamo giving off current* when its armature is mechanically rotated in an *opposite* direction to that in which it normally revolves as a motor, supplied with current from an accumulator; that is, leaving the circumstance of its backward rotation with reversed current out of the question for the sake of illustration.

This principle was first applied to vehicular propulsion—albeit in a tentative manner—by W. H. Patton, of Chicago, who in 1890 constructed a car upon which a gas engine drove a dynamo which gave its current to a small accumulator, which again supplied sufficient current for an electric motor to drive the car actually. This arrangement was not only complicated, but little, if any, lighter than an ordinary electric motor and accumulators. Six years later, however, H. J. Dowsing and L. Eppstein each introduced far simpler systems. In Dowsing's device the surplus power of a petrol motor drove a continuous-current dynamo; which, after yielding sufficient current to charge an accumulator set, became a motor driven by these last the moment the car speed fell below a fixed rate; the motor-dynamo also serving to restart the car. Eppstein's method, on the contrary—which now constitutes one of the three types above mentioned—was to couple a petrol-motor direct to a dynamo; which furnished current to two motors and to a small battery connected in parallel with the latter. At moderate speeds both shared the current, a reserve being created in the accumulator in this way—the accumulator thus acting like a flywheel—which was absorbed by the motors at high speeds, ascents, and overloads generally. Again, on a gradient, the motors acted in two ways, braking the car and acting as dynamos to recharge the accumulator.

A second type is that of Lohner and Porsche, who hitherto have used no battery, but couple a petrol engine direct to the armature of a dynamo with a circular field-magnet, rockable axially, the rotation being controlled by springs. The armature thus acts mechanically as a flywheel, and the field-magnet to a certain extent as a governor; since the latter overcomes its spring when the load on the dynamo exceeds the normal. Both are connected to a controller, whence the power is transmitted to motors enclosed in the hubs of the front wheels of the car. It will thus be obvious that the armature has nevertheless none of the physical power-storing properties of the Eppstein (or Fischer) system, for which reason a small supplementary battery —large enough to store sufficient power to start the petrol motor per dynamo, and for ignition of the former —has latterly been employed on Lohner-Porsche cars. It is not, however, of sufficient capacity for recuperative purposes, although the motors act as brakes on a descent; but the system is much lighter than the one first described.

The third type of compound motor is the Germain.* In this the petrol motor is connected to the field-magnet of a dynamo, the armature of which is keyed upon a longitudinal shaft on which the armature of a second dynamo is also mounted, the field-magnet of the latter being fixed to the frame of the car. The end of this shaft again carries a bevel gear, which meshes alternately—according to whether the car is being driven ahead or reversed—with similar bevel

* The Germain *electric* car.

gears, mounted on sliding sleeves on either side of the differential gear-case on the cross or counter shaft; changes of direction being thus effected mechanically in the Germain system. Now the armatures of both dynamos each have a separate commutator and set of connections to a controller and variable resistance coil —not unlike the high-tension coil described in a previous chapter, though, of course, with a different function—the armature of the first dynamo thus transmitting the power to the field-magnet of the second one, which thus acts as a motor. But as both armatures are mounted upon the same shaft, it will be apparent that the pull of the field-magnet of the first dynamo—which, as we have seen, is mounted as a flywheel on the petrol-motor shaft—acts directly and mechanically on the armature of the second or motor-dynamo, and indirectly and physically upon it by reason of the power transmitted—per controller and coil—from its own armature to the fixed field-magnet and the armature of the motor-dynamo.

Now, because the field-magnet of the dynamo acts as a flywheel, it follows that the faster the engine runs, the nearer the rotary speed will approach that of the armature; and not only will the magnetism be reduced in both in consequence, but also (*a*) the direct torque on the armature shafting throughout, and (*b*) the amount of current supplied to the motor-dynamo. Thus the combined result is less work done at the bevel-drive. Conversely, the slower the engine-speed, the greater will be the difference between the speeds of the dynamo field-magn[illegible]ts armature [illegible] reverse of the above resu[illegible] Fu[illegible] the resista[illegible]coil is i[illegible] dynamo and the second, so as to create a resistance "across" the field-magnet of the latter, which slightly short-circuits them. Further short-circuiting naturally increases the current in the main or dynamo circuit, and consequently the direct torque of the dynamo; these changes corresponding to similar increases in the work done on the bevel-drive, and hence in the speed of the car, the effect on the top-speed being that of a direct through drive in an ordinary car. Indeed, the Germain system is practically an electric change-speed gear, its advantages being greater flexibility and variety of speed-changes, and smoothness in making them, there being no risk, as in ordinary cars, of tearing the teeth of the gears out. Indeed, it must be admitted that the almost universal system used in the latter, of sliding toothed gear-wheels, revolving at high —or, indeed, any—speed, in and out of mesh with one another, is nothing less than barbarous, mechanically speaking. Unfortunately, it is only within the last two years that anything better in the way of mechanical change-speed gears has been devised. These are the Ricci gear, which will be referred to later, as well as the recently introduced Barber device.

Other applications of the alternate dynamo-motor principle are those of Fischer, Munson, Hart, Mildè, Jenatzy-Martini, and Pieper; but though it may be taken for granted that all show some reduction from the weight of the electric-motor pure and simple, and certainly render their cars independent of the charging station, it is equally certain, from the nature of their construction, that any complications, mechanical or physical, which may belong to either the electric or the internal-combustion motor are combined in the compound motor. And the lightest compound system, it must be remembered, weighs some 40% more than the average internal-combustion motor. Therefore, while these differences exist—and it seems only too probable that they will not only continue to do so, but increase in relative percentages of advantage and disadvantage, especially in view of the introduction of better systems of mechanical change-speeds—it is unlikely that the compound motor, so far from assuming equal rank with the internal-combustion engine as a motive power for road vehicles and small vessels, will even displace steam in that capacity.

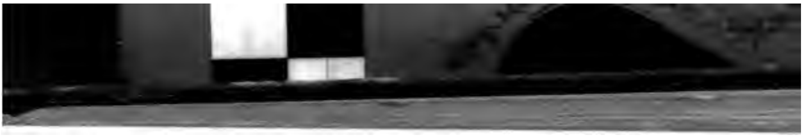
Part III

CONSTRUCTIONAL

CHAPTER IX

DESIGN AND CONSTRUCTION OF MOTOR-BODIES

IN the preceding chapters the working and constitution of the various motors adapted to automobile purposes have been fairly extensively dealt with, thus shortening the necessary discussion of their design, construction, and installation. Indeed, in the case of electric motors, constructional details have been treated fully enough to render their further description needless for the purposes of this work. And throughout, types rather than examples have been described hitherto, since only their working was being explained, examples and structural details only being introduced to typify or illustrate variations of *working* principles or systems. These, though normal enough in themselves, might easily, if left unmentioned, have confused the reader who subsequently chanced upon them, on account of their wide variation in *construction* merely, from the one or two standard types with which he would be familiar, had these latter only been described. Yet when we



come to design and construction, even the bare outlines which it is proposed to give, we find that internal-combustion motors vary so greatly in these respects, and that each type of construction presents advantages and disadvantages which affect its working to such a degree, that mere description in the mass no longer serves our purpose. Thus detailed discussion becomes necessary, if we are to gather any idea of the nature of these advantages or disadvantages; and especially in order to understand the conditions and methods of practice which now obtain in the automobile industry.

There are, perhaps, no two technical details more popularly discussed than the bore and stroke of motors, and their horse-power; and there are, perhaps, none of which the relative effects and governing conditions are more confused in the minds of the non-technical public, who seem to imagine (to give an example) that the installation of a motor of, say, twenty horse-power on a car means that the whole of that power is transmitted to the road-wheels, or is being uniformly exerted or developed at the wheels at all speeds; or what not. Others, again, appear to think that if the content of a cylinder is so much, that so much horse-power is developed, and that the same conditions operate, to the same extent, *irrespective* of the relative ratios of bore and stroke, amount of compression space, and a score of other details, physical and mechanical. And since professional men—either engaged in active production, or as consulting engineers, constantly engaged in all manner of laboratory and workshop tests—have not yet arrived at the same conclusions as to the relative values of these conditions, and are still experimenting, busily as ever, with the view of producing the most efficient motor some day, as a standard type, it is clear that the lay public must rely, for some time to come, on the varying information they can glean from the trade. And, generally speaking, they are in safe hands, since the latter, to do them the barest justice, do more to meet their clients, and give them value for money, than could be expected from them as business men, and that in countless instances. But it is equally clear that no one as yet can afford to dogmatise where motor theory is concerned, although one may criticise mechanical practice.

Nevertheless, the slight outlines of both which I propose to give, to the best of my present knowledge, may, in addition to what has been already written, enable the reader to understand what has been done, as well as the lines of present practice. Now, in 1862, Beau de Rochas laid down the following four essentials for internal-combustion engines of the compression type: 1st. Maximum of cylinder-capacity for minimum diameter: because the greater the diameter—for a given combustion-chamber length—the more heat-units wasted and power lost through radiation. 2nd. High compression: because this diffuses the inflammable particles more intimately through the cylinder-charge, thus promoting (*a*) greater rapidity and thoroughness of combustion, and (*b*) a greater expansive effort for a given charge; hence greater power and economy. 3rd. Length of piston-travel to produce the results of the second essential just detailed; and also a quicker charge induction and a more thorough exhaust-scavenge, as well as to counteract the known weakening of the effort towards the end of the stroke. 4th. High piston-speed, in order to multiply the effort produced in a given time ; hence (*a*) greater power stored in the flywheel rim, or (*b*) equal power with a lighter flywheel, and (*c*) less vibration. Now it might be considered that these principles, carefully followed out, would result in a lengthy, top-heavy engine, with additional length to reduce the connecting-rod angle of thrust—like the original Daimler motor—and, in any case, noise, jar, and vibration. On the other hand, a short-stroke high-speed engine, with higher power, is equally indicated ; indeed, in the latter part of his pamphlet, Beau de Rochas rather encourages a short-stroke engine with a fairly large diameter and high compression. Singularly enough, too, seeing that the idea was not further developed for the next thirty-five years, he also anticipated spontaneous ignition by high compression of the charge.

Modern designers, therefore, working year after year from Daimler's starting-point, have compromised somewhat as follows :—

FEATURE.	RESULT.
High compression retained by reducing clearance space in cylinder head. Also radiation area reduced to some extent for the same diameter.	Shorter cylinder, and a more compact engine of greater power on the same fuel-consumption. Ratio of water needed for cooling slightly reduced, and amount much reduced, thus again reducing engine weight.
Length of stroke also slightly reduced. Higher rate of piston-speed effected in various ways.	Angle of thrust reduced, also vibration and friction. Greater durability. Greater power, and a much lighter engine for power.

Some designers go even further, and by reducing the stroke to much less than the bore, claim the following advantages:—

A much shorter and more compact motor. Also slightly reducing the clearance space. Diameter slightly increased for same designed motor-power. Possibly increased water-space in jacket, diametrically.	A greater effective piston-area, with the same average of compression per sq. in. Extra power claimed. Possibly some loss by radiation. About the same weight of water.
Still higher piston-speed.	Probably greater fuel-consumption, but much greater power = a lighter motor for the same power, and smaller fuel-consumption.

Continental designers, on the contrary, do not admit these conclusions to anything like the same extent. The majority prefer speed increased by other means, or a comparatively slower engine, recognising the fact, in the latter case, that the theoretically higher horse-power gained from increase of r.p.m. is lost in practice by the necessity of mechanical reduction by gearing. They therefore retain an average proportion of 7 or 6·5 stroke to about 5 bore. British designers, nevertheless, appear to admit these results to a certain extent, judging from their practice, in the majority of instances, of making the bore equal to the stroke. Others, again, go farther —as in the Standard engine, one of the latest—and make the stroke less than the bore in a ratio of 3 to 5 or thereabouts. In this motor the speed-range is from 250 to 2,000 revolutions per minute, so in this respect it would appear that the short-stroke design does

not fail. At the same time, the example named must be classed as a high-speed engine, as its r.p.m. for normal h.p. is 1,200. Yet, whatever question may be raised in regard to the comparative merits of the short- or long-stroke type, the former possess one advantage not usually found in vertical engines, namely, that the carburettor can be bolted on the head, right against the inlet-passage opening, and still be gravity-fed, thus reducing the length of the induction. This has been recognised as one of the chief points in favour of the horizontal type of motor, such as the Vauxhall, Wolseley, Pick, and many American and Continental examples; for, in those instances in which the carburettor has been thus placed on a long- or equal-stroke vertical motor, the fuel has generally been pressure-fed to the float-chamber. This was the case, if I remember rightly, in the earlier English and French Daimler motors.

Personally, I have no settled convictions as to the relative advantages or disadvantages otherwise of either short-, equal-, or long-stroke motors. Nor is it any part of my present purpose to canvass them further than in the previous table, which must be taken as a mere statement of claims. *In medio tutissimus ibis.* It may, however, be said that designers endeavour to balance mechanical against physical advantages, and combine both as far as possible, looking rather to improvement in other details of construction for any increase of efficiency. The present tendencies in this direction, in Great Britain at least, are first of all to simplify and reduce the number of working parts wherever possible, and to render them more accessible. Now, in regard to this much-discussed matter of complication, it must be understood that so long as they make little difference to the cost of production, and are soundly constructed, and do not reduce accessibility, it does not follow that so-called complications reduce efficiency. On the contrary, some of the most efficient machines in the world, so far as the multitude of their working parts is concerned, appear complicated to an alarming degree. Take, for instance, a wool-carding machine, a linotype, or a French express locomotive, what could be more efficient, each in its own line? In this connection it is curious to note that some of the most hypercritical British critics at the recent Salon d'Automobile had actually been drawn to Paris in time for dinner by one of these terrible French engines.

Still, the great thing to remember is, that as each working part constitutes a link or bridge in the path between power and work, it represents a point, the failure of which will break that path. Therefore the fewer such risk-points occur in any device the better, so long as the capacity to perform a given task efficiently be not impaired. On the other hand, we must distinguish between an apparent complication which is an improvement, and one which is a mere alteration. The former we may welcome, so long as it does not lessen accessibility to the "innards," which is, after all, one of the chief objects of modern design. Another important object—both from the producer's and the purchaser's standpoint—for which designers are striving, is easy replacement of all parts of the motor when faulty, worn out, or damaged, so that the whole need not be condemned because of the failure of one part. Thus many makers on both sides of the Channel are building their engines up in singles. These are being also made in one, or at most two, measurements of bore and stroke,

thus standardising production and reducing its cost; power per motor being increased merely by adding one or more cylinders. The most notable example of this practice is the Weller motor, in which not only cylinders, but the crank-case are made in singles, so as to facilitate such addition. This practice also enables working parts, such as pistons, valves, connecting and tripping rods to be standardised in size for all motors of the same make at least; the same also applying to bolts and nuts. Ultimately the purchaser gets the benefit of a cheaper motor, of equal or better quality.

Furthermore, the greatest efforts are being made to improve carburation by the use of such carburettors as give a constant proportion of atomised fuel and air in the inflammable mixture at all variations of speed. These devices act, not so much to increase the actual volume of air in the mixture—although this increase is a secondary result in many instances—as to decrease its velocity at high speeds past the fuel-feed jet. This high velocity, it must be understood, increases the vacuum in the carburettor and induction pipe, and creates too great a flow of the more inert fuel, thus making the mixture too rich. Throttling at the mixture induction is no use, because, to say nothing of wire-drawing the charge and losing power thereby, it increases the air velocity still further, the piston-suction being constant. Therefore a still more disproportionate amount of fuel is drawn into the mixing chamber and atomised, and having, so to speak, got under way, on account of its greater weight, continues to flow, after the air has ceased to flow because the inlet valve has closed.

It does not return, of course, the result being that this undue enrichment is continued and fuel wasted, even for a few strokes after the engine has been slowed down. Now, when any vacuum is produced inside the carburettor, the air-pressure therein is reduced below that of atmosphere. Commandant Krebs, taking advantage of this fact, fitted an auxiliary air-inlet above the air-intake, this inlet being surrounded with a sleeve attached above to a small vulcanite platform, beneath which again is a spring acting upwards to keep the inlet closed. Thus when the pressure inside the carburettor falls below a certain point, the atmospheric pressure on the platform depresses it, overcoming the spring and opening the air-inlet. This action may be compared to the pushing of two persons on either side of a door. The result, however, is that the vacuum and fuel-velocity are reduced to normal. Mr. J. R. Dunlop, again, also achieves this with a saw-like blade in the fuel-jet, the teeth of which turn the fuel-flow back on itself when its velocity exceeds the normal. So do Chenard-Walcker and Prunel, in whose carburettors a sprung air-valve is seated centrally in the mixing chamber, so that the lift may correspond at all times to the piston-suction—Huzelstein or Lunkenheimer fashion—thus keeping the vacuum and the height of the fuel-spray constant. All these devices are automatic, but may vary with the spring tension. Others, again, throttle the fuel-jet from the governor, thus mechanically producing the same effect.

Another great feature of modern practice is the endeavour to eliminate, as much as possible, the power-wasting effect on the change-speed gearing, and to obtain a greater variation of speed than these gearing systems typically afford. To do this the gearing is so arranged as to give a direct drive through from the

engine to the transmission-shaft or driving-axle—as the case may be—on the top speed, the speed being subsequently reduced or further increased by slowing or accelerating the engine, the lower gears only being brought into action for steeper rises than is good for the motor to negotiate. The latter, in all but seven examples, so far as I am aware, is slowed by throttling the mixture; which, as I have tried to show, is not good practice: for this throttling is entirely different from the throttling of steam in its physical results in the engines, as was argued in the chapter on steam motors. In the Chenard-Walcker car, however, the speed is reduced by the action of special skew-faced inlet-valve cams, mounted on a cam-shaft which can be slid lengthwise against a spring—not unlike the cam-shaft of a Serpollet engine—the sliding of the shaft thus causing the skew-faced cams to lift their rods *always to the same extent*, the motor being slowed by varying the *duration*, *but not the extent* of the opening of the inlet valves. Thus the cylinders are free to inspire their charge at the same velocity at all speeds, power being reduced by cam-variation to reduce the charge amounts, but *not* by wire-drawing. In this way practically any speed from a two-mile crawl to the fifty-mile maximum can be obtained without touching the gears, and with an *unvaried* mixture. The Chenard-Walcker engine, therefore—in my opinion at least—may be regarded as having the most soundly induced flexibility—theoretically speaking—of any now constructed, if indeed it is not the most efficient of all. So far it is certainly unique.

The latest constructional departure is the new Hutton car, which is fitted with the Barber variable-feed change-speed gear. This—which, as well as the Ricci and other

devices, will be described later on in detail more fully—enables the motor to be run at a constant maximum speed at all times, irrespective of car speed, for the first time in automobile history. The speed changes are effected by varying the throw of an eccentric linked to a sliding-sleeve keyed on the motor-shaft end, and supported between two clutch discs—one of which is secured to the driven shaft—held in perpetual engagement with each other, and with either side of the eccentric, through clutch shoes attached to opposite pairs of link-arms on its strap. Thus the sleeve, sliding in and out of the motor-shaft clutch-disc—which is held stationary in a circular casing, and itself contains the other disc—not only rotates the eccentric to give it the rotary drive, but varies its throw to give all speeds from rest to maximum. It will therefore be seen that flexibility is not at all essential in the motor, the speed of which, nevertheless, can be reduced—to correspond with an increase in the eccentric throw—to reduce the fuel-consumption per mile on the level. This last device constitutes the latest radical development of construction—in fact, at the time of writing the Hutton cars are scarcely on the market—but another, though less recent one, is to place the change-speed gear-box at the other end of the driving-shaft, forming it, in fact, as part of the casing of the differential and bevel drive on the rear axle. The Henriod "Pandora" and a very recent Simms gear-box are the most popular examples of this system, which gives a direct drive through with perhaps the minimum loss of power attainable with spur gearing.

Other objects of present effort are the lightening and strengthening of the car frames or chassis, the strengthening of the driving axle and its differential gear casing, the simplification of the controlling mechanism, and the improvement of tyres in various details. These, however, will be discussed subsequent to the actual manufacturing processes relating to the motor itself, which will be the subject next considered. We note, first of all, that the frame and body of a motor, apart from its working parts, consist of castings, the cylinders and heads being cast iron or steel—though in some instances the water-jackets are made separately—while the crank-case may consist of iron, steel, aluminium, or magnalium castings, or of any other metal of sufficient strength; lightness, of course, being sought as well. All castings are made in moulds, consisting (*a*) of the core-body—thus termed to distinguish it from (*b*) the sand-core proper and (*c*) the core-print. The first regulates the shape of the inner surfaces, assisted by the second; while the third moulds the outer surfaces to the shape of its own inner surfaces. These parts, which are called patterns, are generally made of steel, brass, or compo-metal to ensure freedom from warping, strength, and a smooth surface to which neither the hot metal nor the sand of the core will adhere—their surfaces being also coated with blacklead to assist this result—thus obtaining regularity of thickness in the casting and reducing the labour of finishing.

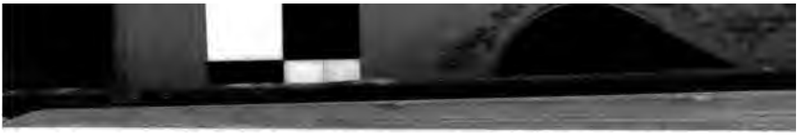
These patterns are formed differently, usually with the core-print and sometimes the body halved or otherwise divided for convenience of extraction, *i.e.* relief, according to the methods in vogue at the individual foundry and the nature of the casting to be made, quite apart from their actual shape as pattern moulds. But in all cases they are formed so as to leave blank

spaces where there is to be metal in the casting, and *vice versâ*. However, when there are to be intermediate blanks in the casting (*e.g.* in the water-jacket), intermediate core-bodies are introduced, and supported by stays between the inner-body and core-print, so as to mould the sand-core, which consists of fine black cohesive sand, capable of being moulded into solid masses which will retain their shape. These bodies have holes at one or more points, and are pierced from the centres of the holes so that they may be withdrawn from the moulded sand-core, which runs through the holes to the walls of the outer mould to form stays or supports—the sand-pegs—for itself. These sand-pegs leave holes—the vents—in the outer walls of the casting, which are afterwards plugged, except, of course, in the instance of the water connections, and those openings, such as the inlet and exhaust passages, valve-box seatings, etc., which make complete connection with the interior. Through these vents and openings, then, the sand is withdrawn when the casting is cold. Sometimes, too, when the connection is to be short and direct, as for the sparking-plug, the sand-peg may be replaced by a removable mould-plug between the outer mould and inner body.

The core-print or outer mould having been placed on the moulding-floor, and firmly secured, the inner bodies or core-prints proper, the thicknesses of which correspond with those of the intended castings, *e.g.* the inner and outer bodies of the head and cylinder and their water-jackets, are then secured in position, after which the inmost body is erected centrally, and secured by the keys or mould plugs previously mentioned. The outer core-print also has two or more holes to support the casting, but these holes, of course, are covered. The prepared sand is then pressed, little by little, firmly into all the blank spaces in the bodies, and between them and the inmost one, and after the core has thoroughly set, the core-print bodies are withdrawn. As before remarked, their surfaces have been blackleaded freely, thus leaving smooth surfaces on the cores, which, when sufficiently dry, though still slightly damp, are ready for the metal to be poured in. The utmost care is, or should be, taken in the selection of the metal, in regard to its grain and heat- and wear-resisting properties. Presuming all this, however, the molten metal is poured in steadily, but little by little, and the casting made, and allowed to cool gradually.

Obviously, the operation of making the core and relieving the print, to say nothing of the actual casting of the specially grained and chemically constituted metal used, is difficult enough even when the sand is of the best, and print and body are liberally coated with blacklead—unfortunately the blacklead is too sparely used in many foundries—to prevent either sticking when withdrawn, or the core sticking to the casting. And if this is so, when only the cylinder head, or heads, and valve-chests are formed in the casting, with their water-jackets, it will readily be understood that it is even more difficult—indeed, an almost prohibitive task without the greatest skill and experience—to cast not only these, but the cylinders and water-jackets, in one casting with few or very small openings. For, to say nothing of the chance of pinholes forming and making the whole casting a "waster" (often not detected as such until machined to a finish and tested as a motor), there is the difficulty of getting all the cylinders in perfect line and all the thicknesses as designed, else when bored the walls of the latter will be too thin at one point or another. This even worse fault obviously cannot be detected except by the resultant short life of the cylinders. Consequently, cylinders are cast in pairs, or at most in threes in this fashion. Cast in singles, a faulty cylinder does not involve the scrapping of the whole job, this system being therefore the better commercial practice.

Yet it cannot be denied that the whole affair is pretty to a degree when finished; but unless the plugs are made removable, a fault develops in the water-jacket later; that is, earthy silicious constituents of the water bake hard on the cylinder, and cause unequal cooling and expansion, and consequently structural deterioration, the pump being frequently blamed for failure when the fault lies in the dirty jacketing. Seldom, too, are spaces left between the cylinders, the same results, in my opinion, accruing. However, all these faults may be eliminated by casting the jackets open at the sides or ends—English fashion—or at the top, as in some of the latest French productions, the opening thus made at the top being (*a*) formed into a seating for a cast-cap, or (*b*) fitted with a light metal panel, packed and screwed or bolted into place. Water-jackets with side or end openings are also panelled in the same way. Frequently, also, the cylinder head is cast open and seated or tapped for a cap, held down from the water-jacket cap, which is yoked to place. This, however, although it enables the thicknesses to be checked to a nicety, may mean leakage, unless the greatest care is taken, not only in the machining of the seating, but in its setting on and yoking down, unless the cap be screwed in. But in all these cases the casting is easier



to make in the first place, although another objection to the open-top style is that the valve-chests must be at the side, and so give the motor a top-heavy or else bunched appearance, which is increased by the exhaust and induction pipes. This is, of course, a mere matter of taste, but the principal objection urged against all methods of casting cylinders and heads in one piece with closed tops is that the cylinder cannot be bored true for the whole of its length. Personally, in view of the working conditions of boring, I am inclined to question this opinion, except with a very long cylinder.

Another system in constant use is to cast the cylinders and heads separately, each with its own water-jacket, the water-jackets communicating through holes in a metal-to-metal or packed joint. The advantages are, of course, easier casting, and the greater ease in boring the cylinders absolutely true. One is also more certain of the thicknesses, especially when the water-jackets are open-panelled. Against this, however, must be set the fact that the frames or faces around the cylinder tops and on the underside of the head-casting, which constitute the joint, even when freely opened, rather check the rapidity of the water-circulation; and that leakage of water *into* the cylinders, or loss of compression *from* them, are liable to occur even when the joint is carefully made, if the contraction of the heated metal be at all unequal when the motor has cooled down after running, mere surface-packing soon perishing. Personally, I consider, both in this instance and that of pinholes in a "headless" casting, that it is not so much leakage of water into the cylinders that does damage and causes engine-failure—water is actually sprayed on purpose into Banki's engine—as that compression is lost through these leakage points into the water-jacket. And I base this belief on the fact that the pressure inside the cylinders, even before ignition, is about four times as great as the pressure of water in the jackets. Therefore, as this failure, either way, does occur, one would favour a variation of this method, in which the cylinder-jackets are cast open all round at the top, as well as the undersides of the water-jacket of the head-casting, the former, as well as their cylinders, fitting into little channels in the metal faces of the head-casting and its jacket, cut fairly deep, so as to contain a little asbestos or metal packing (see Figs. 6 and 7, p. 46). Or the little channels can be cut in the metal faces of the tops of the cylinders, to take corresponding flanges or ridges on the face of the head-casting. Thus leakage in either case is out of the question, the heads being secured to the cylinders by the usual short bolts seated in the latter, or by colonnette bolts from the crank-case.

This method is blended into another system, seen in some of the latest Continental examples, such as Panhard, Tony Huber, and Germain.* In these, the heads are cast separately with their water-jackets, with channels into which flanges on the cylinder tops, and also the cylinder water-jackets, are fitted; the usual short bolts securing the heads to the cylinders. But the peculiarity of this construction is that the cylinder-jackets are not cast on. Instead, they consist of light, separately made cylinders, barely one-eighth inch thick, of copper, brass, or white metal, frequently corrugated in order to permit expansion at the higher circulation pressures experienced at high speeds. They are, furthermore, bevelled off at the bottom, so as to fit closely to the cylinder walls, on which they are sweated down and soldered. Their upper edges, as said, fit into the channels in the joint-faces of the outer walls of the head water-jacket.* In the Panhard motor they are held by the joints between heads and cylinders (see also Figs. 6 and 7, p. 46). There can be no question as to this being a light and lovely construction, and the soundest commercial practice; moreover, it is free from the common defect of over-water-jacketing. Again, when the heads are held down on their cylinders by colonnettes or corner bolts from the crank-case, the whole device is rendered extremely easy to dismantle or reassemble. Furthermore, with this construction cast-iron or steel tubes—practically liners—can be used for cylinders. These are said to be not only lighter, but cheaper than the usual castings, and also to require much less machining. This system, too, shares the advantage of all motors built in singles, of ready replacement of a spoilt cylinder.

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* The Germain cylinder-heads make a double-coned pipe-joint, with their cylinders.

But it also has the disadvantages common to the type, namely, that stays are required between the heads—with, of course, an increased number of bolts—in lengthy, long-stroke, multi-cylindered examples, in order to strengthen the whole motor against its own vibration, unless, as in the Weller motor, all the exhaust and all the induction pipes are made in single castings, which serve as a bond. Still, there are twice the number of joints in the water-connections, and these water-jackets, it is said, become very leaky after a time. Of this detail I have no experience, but if so, I see no reason why all these disadvantages should not be eliminated (1) by casting all the heads and their water-jackets in one, with packing channels on its underside. (2) By screwing the cylinders one by one into a light metal frame with a channel cut round the outer edge of its upper face. This frame would hold all the cylinders midway up. (3) By water-jacketing the whole as one cylinder with a continuous jacket all round, which, being held in a packed channel at top and bottom, obviously could not leak, and would only need one or at most two water-connections. (4) Securing the head to its cylinders by two colonnettes at each end—or even a single large one—from the crank-case to lugs in the head casting, the cylinders being also screwed into the usual feet, or set into raised annular channels in the top of the crank-case. Or the colonnettes could be arranged one at each end and side, so, with only four nuts to loosen, apart from removing the exhaust, induction, and water-connections, inevitable in any motor repair (such as fitting fresh piston-rings or a new cylinder), such operations would probably be reduced to bicycle simplicity. Other advantages might be cited, but cheapness, ease, and lightness of construction, with facility of renewals, would appear the most salient. Nevertheless, I quite expect that this suggestion will be severely dealt with by the omniscient "expert"; only I would remark that it is merely an extension of the latest successful bicycle-motor practice; so if it succeed in that capacity, what is to prevent it doing so on a bigger scale, with scantlings proportionately increased?

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* The water-jackets in the Germain motor are fitted on an [illegible]tions, on the cylinders, with rings shrunk on outside. These [illegible]

Another variation from general practice is to be found in the Napier motor, in which the upper half of the crank-case is extended upwards to the head, forming water-jackets and cylinder walls, into which cast-iron liners are forced down. Lastly, when cylinders are cast in pairs, the inlet passages are also paired, by being situated between the exhaust openings, so that they may branch from a common opening in the centre of the valve-chest, thus materially reducing the length of the induction pipe.

Coming next to the crank-case castings, we find the lighter metals previously mentioned employed instead of steel or iron. They are formed in two main castings, *as a rule*, so as to halve the crank-case either (1) vertically, the halves being bolted together, as for single-cylinder motors, or (2) longitudinally, the halves being cast open at their ends to receive disc-like plates containing the end-bearings of the crank-shaft, or cast to form seatings for the bearings; which are made of phosphor bronze or some other alloy of anti-frictional metal, and should be of considerable length, in order to distribute the shaft friction or thrust over as wide an area as possible. In order to reduce this friction, these bearings, which are bored true out of the solid block as a rule, though sometimes cast to shape and bored true, and in any case flanged to their seatings, sometimes have one or more transverse grooves at their ends, containing a number of steel balls. The number of these balls is just short of filling the grooves, so that they may move without crowding each other. At the ends where the grooves are cut, the diameter of the bearings should be increased to admit of the shaft being thickened into an extra shoulder, to prevent it being cut and weakened by the balls in wear, as these naturally take its thrust only at their contact points. Indeed, ball-bearings are the merest fad, in my opinion. Furthermore, the rest of the bearing will take the thrust better. In all car-motors, and many of the marine type, the upper half of the crank-case casting is formed with arms or long lugs cast on either side at each end, and in most multi-cylindered examples with one in the middle as well. These arms, which vary in shape and angle with the general design of the motor, attach it to the frame or bed-plate of the car. They also, in some examples, are cast so as to form buttresses for the crank-case.

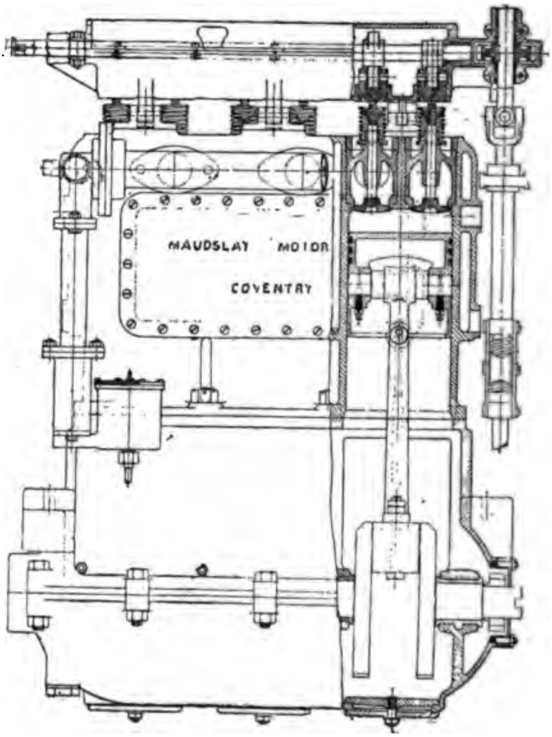

FIG. 16. THE MAUDSLAY MOTOR
SHOWING CRANK-CASE AND WATER-JACKET PANELS

Inside or outside the latter, again, small lugs or projections are cast uniform with it to form the seatings of the cam-shaft bearings. If the cam-shaft is carried outside, a covering is also cast and bolted to the crank-case. It is usually mounted inside, however, to protect it from dust and dirt, and for more convenient lubrication; also, this upper half of the crank-case is cast open to receive the covers of the half-time gears, or the governors, or the commutator, or all three, or is even shaped at its ends so as to include them.

Again, the whole of one or both of its sides are often cast open, the edges of the opening thus formed being counter-sunk to receive a removable inspection door or panel, which thus actually forms the side when secured in place. In other examples, inspection openings are made in line with the cranks. Thus the condition of the shaft bearings and connecting-rod brasses can be noted, and repairs effected, without dismounting the motor, or breaking joint between the crank-case and the cylinders, or between the two halves of the crank-case. Now, as these joints are ordinarily among the most difficult of the fittings in assembling the motor, it will be readily seen that this method of crank-case construction is the soundest practice because of its convenience. As has been said, it originated with Leon Lefebvre. But we shall note that many makes of Continental motors, especially among those most in fashion and most extravagantly boomed, afford no such facilities for inspection and repair. Instead, the whole mechanism is enclosed in a crank-case—halved as above described—without a single opening except from beneath, so that the entire motor has to be dismantled if the slightest part go wrong in any way. This construction would therefore appear unsound, both in an engineering and in a work-a-day sense, even for a little bicycle motor. We can, however, admit it in the latter case, on account of its small size and accessibility. But in the big multi-cylindered engine of a touring car, especially when surrounded with the necessary branch lubricators, the exhaust and induction pipes, etc., etc., what shall be said? Buying a motor, therefore, with a crank-case thus hermetically sealed, in my opinion, is tantamount to buying trouble, let it run never so sweetly while in good order. Breakdowns do not occur in garages, but usually in situations when the roadside or a hedge is the site of the repair-shop thus suddenly constituted. And what inspection, I would ask, can be effected with any certainty through a hole in the bottom of the crank-case? And if these everyday contingencies of automobilism on land detract from the value of a motor, those to be met with afloat, such as a hot tide or half a gale driving a vessel with a temporarily broken-down motor on a lee shore, absolutely disqualify it for marine work.

To complete the description of the castings, the lower half in a multi-cylindered motor usually has transverse webs or plates formed or fitted internally, which form seatings for the bearings of the journals, that is, those portions of the crank-shaft between the cranks. These bearings, therefore, with their supporting plates, are vertical to the spaces between the cylinders above. This lower half, as has been said, constitutes an oil-bath for the whole of the contents of the crank-case, and on this account should be fitted with taps to draw off the oil or openings through which the crank-case may be frequently cleansed.

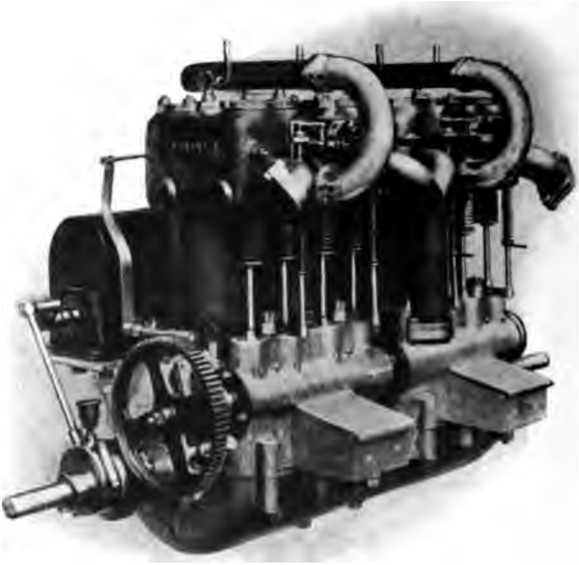

FIG. 17

A TYPICAL FOUR-CYLINDER MOTOR, FOUR-STROKE TYPE

CHAPTER X

DESIGN AND CONSTRUCTION OF MOTOR PARTS

HAVING thus discussed the designs most in vogue for the various parts of the body of a motor, we may enter upon the details of the machining and fitting of the castings. These, after first having their roughnesses, if any, cleaned off, have their faces machined to a true surface whenever a joint of any sort is to be made. This is done in the case of the crank-chamber casting, on a planing machine, or a vertical milling machine; the latter, with cutters of the right size, doing the work about twice as fast. The joint between the halves must be made absolutely parallel with the top of the crank-case. Each half is now bored for the bolt holes, the oil holes to the bearings, etc., in a "jig" or template to assure perfect coincidence. The countersinking for the inspection panels is then milled, and the two halves are now temporarily bolted together and set in a lathe to have the seatings for the end-bearing plates faced, or the holes for those bearings, as the case may be, bored true, as well as the seatings for the bearings on the intermediate plates and for the cam-shafts. These plates, if cast separately and fitted in, are also machined separately, as also end-bearing plates, which are lathed to fit their seatings and bored for their bearings. All these seatings for bearings must be in perfect

alignment and parallel to the top of the crank-case. The bolt holes for the cylinder feet having also been bored to jig, the crank-case is now ready to have its bearings fitted and, if necessary, re-aligned and fitted, and to be put together after a final cleaning up.

The cylinder and head castings, having been cleaned up generally and had all faces planed or milled true, are then "chucked" on a capstan lathe to have the valve-box seating faced and the exhaust-valve seating formed. Other seatings are also faced on this tool, such as those for the ignition-plug—if the motor is to have low-tension ignition—covers, etc.* The cylinders are then put on a turret-lathe, and bored in two borings with special mandrels, the first one giving a coarser cut and the second the finer, finishing cut. This operation, next to the casting—which, in my opinion, is more of an art, since anyone can either "make a spoon or spoil a horn," whereas the founder, so to speak, has to "make the horn"—is the most important in the whole process. One-five-hundredth, and in some works as little as one-thousandth, of an inch is the limit of error allowed.† Some makers, however, fractionally increase the diameter at the base of a cylinder or its crown so as to facilitate the insertion of the piston. Others, again, give an extra finish with a lapping tool, the essential part of which is a rod, with scrap cloth mounted in a holder, or a circular wad of soft material, at one end, not unlike a gun-cleaner. This rod is driven up and down in the cylinder at the rate of several hundred strokes per minute, and at the end of several hundred thousand strokes is found to have imparted a glass-like surface to the inside of the cylinder. Some makers, on the contrary, prefer that the piston should give this in working, but it would appear likely that the glassy surface acquired with a lapping tool would be the more likely to resist the scoring of hot gases from the outset.

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* When cast in pairs, both cylinders are bored at the same time.

† Such is the claim: but I doubt whether less than $\frac{1}{100}$ is attained in actual practice.

After boring, each cylinder is tested by subjecting it to water-pressure internally at 300 lbs. or more to the square inch, when, if any leakage is found to exist, it is rejected. Here, again, a cylinder of the "headless" type, in which the thicknesses cannot be checked throughout, may pass the test, and in further wear expose a partial blow-hole, or fail at a thin spot. The cylinders are then generally given an external smoothing on a lathe, and after having their feet bored for the bolt holes, are ready for the fitting shop. The feet, as we saw, were faced to absolute transversal alignment with the crank-case, so as to bring them to a true parallel, and the cylinder axes to a right angle with the shaft line. In one or two instances, however, the crank-case is so designed as to make the cylinder axes slightly tangential, instead of radial, as usual, to the shaft axis. This is done with the view of eliminating dead-point in the cycle. Similarly the motion of the crank throws—rotary—must always be in a direction parallel to the plane of the cylinders, and at a right angle with the shaft line. As a result, therefore, of all the foregoing alignments and "truings"—continually compared with those of the working drawings—the direction of the motion of the pistons and connecting-rods—reciprocating—is rendered exactly in line, or, at least, parallel with the cylinder axes, and rectangular with that of the shaft. The centres of the crank-pins are also generally

in line with the cylinder axes, but need not be, in which case their connecting-rods are bent over so that their small ends shall be as nearly as possible in line with those axes.

Let us now see what has taken place in the fitting-shop. We shall see that the valve-boxes—which in the case of a.o. inlets always include the seatings, and also include the exhaust valves and their seatings when the valves open downwards from the top of the motor into the combustion-chamber, as in the Maudslay, Selbach, Jenatzy-Martini, Belsize, Buchet, and Duryea—are made in separate castings. These castings are cylindrical, and hold the valve-spindles in central guides, formed vertically on central diaphragms on which the valve-springs are seated. This is the usual construction of single-cylinder valves, inlet or exhaust, but sometimes with a.o. inlets the diaphragms are cast open, and the upper end of the valve-box domed or otherwise closed to form part of the induction passage. Most compound a.o. inlet valve-boxes are of this type. All are secured in their seatings by arms, called yokes or bridges, which in some cases embrace two at a time, being centrally pivoted. Sometimes also, they are secured by threaded open nuts, threaded externally into the metal of the motor-head. Domes of a hose-union type are also used, tightened by a central bolt. These castings almost invariably act as covers, the removal of which enables the exhaust valve to be got at, removed, or ground to its seating. But in motors with valve-chests at the side, with m.o. inlets, unless these latter are operated by the same rods as the exhausts—*e.g.* the Noble bicycle motor—they are replaced in this capacity

by castings which are inspection covers only, and are secured in the same manner.

This constitutes perhaps the one disadvantage attached to m.o. inlets in motors which open upwards

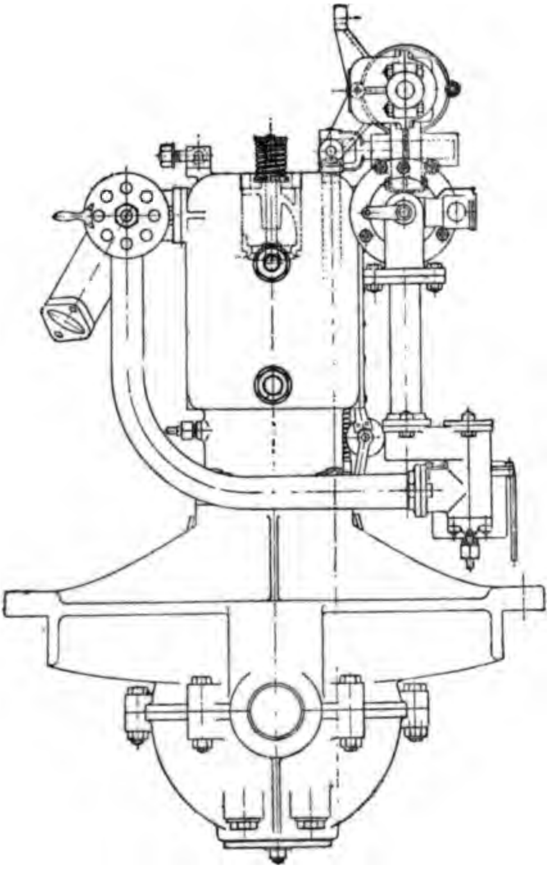

FIG. 18. THE MAUDSLAY MOTOR: SHOWING VALVE SITUATION

from the bottom of the valve-chest, which, therefore, have to be ground to their seatings in the same manner as the exhaust valves. Here it may be remarked that there is actually no such thing as a "water-jacketed" valve. Since it has to open into an induction or exhaust passage, there could not be. What is meant by the phrase is that the water-jacket is extended round such passages, and round the spindle-guides as well in some cases, thus serving, to some extent, to keep the valves cool by conduction. Valves—or rather their heads—are of two kinds, bevelled to fit in a countered seating, and disc valves, which extend beyond the edges of a flat seating. The latter, it is said, are very difficult to grind to a gas-tight fit, and, at any rate, are very seldom used. It is important, however, whatever their material—cast iron chilled hard and expanded red-hot on a steel stem, nickel steel-heads on steel-stems, or rolled nickel-heads on steel-stems—that their seatings should *not* be flush with, but some distance above or below, the walls of the passages, especially the exhaust.

Otherwise their stems will be bent or broken at the neck by the rush of the gases; for it must be understood, from the very heat of their situation, to say nothing of the rapidity with which they act, that they are in no condition to stand anything but a direct flow all round. Furthermore, a flush seating exposes their necks—their most delicate part—to the direct action of the exhaust gases. Of course, this sunk seating—unless it be domed—forms a pocket for combustion products. This constitutes another advantage for the method of placing the valves centrally in the cylinder head, to open directly downwards, since the rush of the exhaust gases can hardly fail to be even all round; so in such cases the seatings are better flush with the cylinder head. Furthermore, this construction obviously does away with lengthy port passages, which decrease power because they increase charge-velocity and may cause condensation. As to the size of the valve-openings, it may be said at once that it varies according to the bore and stroke of the cylinder and piston, as also their lift. However, the inlet-valve opening should at least be large enough to ensure a proportionate charge at all speeds; and if it be for an a.o. valve, it is safe to increase its diameter on account of its unreliable action. In my opinion, the exhaust valve, and still more its passage, should be larger than the inlets, within reasonable limits. In any case it should be large in proportion to the bore and stroke, so as to avoid any throttling and hasten elimination of the exhaust gases. And in all cases in motor construction, the greatest care is, or should be, taken to ensure the boring of the valve spindle-guides to an absolute right angle with the valve-seatings, and to make each a close, yet easy, fit for the spindle itself.

Ignition plugs, which are also castings, are machined to fit in their seatings in the cylinder head in the same manner as valve-boxes, and are also bored to receive the spindle of the rocking-arm of the rupture-spark mechanism, the spring and rapid cam of which they also carry. As has been explained in a previous chapter, their situation and the details of this mechanism vary in nearly every make. In most cases, however, their outer ends are shouldered to fit over their seatings, or in some makes—a neater job—to fit into a shoulder seating of corresponding diameter. In others they are coned to their seatings; and all are tightly secured in place by short bolts or screws, or by yokes. When bored so that the rocking-arm spindle fits properly, no compression is ever lost through this low-tension plug, in my opinion, despite all statements to the contrary by opponents of that system of ignition. These people find their answer in the fact that it is now superseding the high-tension system almost universally, on account of the greater power afforded by the larger spark and the greater ease of obtaining synchronous ignition in multi-cylindered motors, in which high-tension ignition until recently has been notoriously unreliable. All joint-faces are also machined true, and where the attachment is made by bolts or screws the holes for these are tapped in the casting of the cylinder head, or rather in its water-jacket walls, which are thickened inwardly at these points for the purpose. Similarly the holes for the sparking—or insulated plugs—are drilled and tapped, but with a somewhat larger thread than in the last instance, the surfaces also being faced—planed or dressed—true to fit the plug shoulders.

Pistons, as will have been gathered from preceding chapters, are cylindrical, or rather trunk-shaped castings, usually of a special grade of cast iron—though nickel-steel, I believe, has been used—with two internal projections opposite each other, which are subsequently bored out to hold the gudgeon-pin. The situation of these in the piston varies, being frequently above the middle point, although in the Panhard, Hautier, De Dion, Ader, Gillet-Forest, Turgan-Foy, and other French motors, as well as the Maudslay, Brooke, and others in this country, they are placed exactly at mid-point. In one or two they are placed below it; but it is said that this practice engenders rocking in wear. Beneath these

horizontal projections are vertical ones, which are also bored to take locking-screws or pins, which hold the gudgeon-pin; not so much to prevent it rotating as to hinder it moving lengthwise either way, and scoring the cylinder walls to create loss of compression, etc. After these borings have been made, the grooves for the piston-rings are cut—usually two, three, or four at the upper end, and one just above the lower third part or thereabouts—and the piston is machined to the most careful fit in the cylinder.

The grooves are cut, in many instances, to a varying depth, in order to keep the piston-rings from sliding round in work until their openings—which are usually diagonal, but sometimes step-jointed—coincide, thus losing compression; but chiefly this is done so that the rings may be made thicker opposite their openings to give them the even, all-round spring they should have. Sometimes, too, they are pinned at some point in their circumference to prevent their sliding round. They are made of specially grained cast iron, of a heat-resisting quality, and spring into their grooves one by one, beginning at the lowest of the series, the bottom one being sprung on at the other end. In making these rings, after they have been cut and their joints made, each is placed in a circular clamp and lathed out to the proper size inside; it is then secured to the face-plate of the lathe, and worked down to the proper size outside.

Some pistons have internal annular flanges lipped upwards, which catch the oil and convey it to the cylinder walls through holes cut in the trunk. Indeed, there is nothing to prevent the lower part of the trunk being lightened or skeletonised by free perforation of

this kind, so long as the gudgeon-pin is carried
ciently above mid-point to equalise the balance,
upper rings are quite sufficient to check any loss o
pression. Hautier also does away with gudge
locking screws—which are always liable to jar l
by placing a piston-ring over the ends of the gud
pin. Another very neat method of holding the gud
pin in place—one which is very suitable for the s
pistons of short- or medium-stroke motors—is
employed in the "Wolverine" marine motor and
trated in Fig. 19, with the accompanying conne
rod. As will be seen, a groove is cut in over the
of the pin, through which passes a small clamp-
one side of the connecting-rod end, which is sp
made larger to give room for this bolt. Fig. 1
shows the pin fitted.

In the construction of the crank-shaft, too, we
note great variations. When made in a one-piec
forging the cranks are usually represented in the
by solid blocks forged integrally with the main
of the forging, set on it radially at various angles
one another. Sometimes, in the case of the sh
a four-cylindered motor, they are set at an angle
However, in the majority of four-stroke engines o
size they are set in pairs—two up and two dow
180°. The pairing, again, varies; as the end and
ones may pair, with a journal and bearing between
or between the first and second, and third and
cranks; or they may pair two and two, with a c
bearing between the second and third. Three-cylin
motors—or those with six—have their cranks set a
on the shaft, with a journal and its bearing be
each. Two-cylindered motors, also, may have a co

crank for both; or have both in line with a central bearing, or have one up and one down at 180°. Some of these have a central bearing; in others, the inner arm of one crank is extended to form the corresponding arm of the opposite crank.

This construction is common in four-cylindered motors with the cylinders paired; the central bearing thus being equal to a common end-bearing for each pair, which are thus paired ends and middles. Furthermore, in some of these, such as the Napier and Thornycroft petrol motors, these extended crank-arms and those to the central bearing are angled laterally to their pins and journals; this being supposed to enable the shaft to bear the twisting strains better. Personally, I regard the system of a bearing between each crank as the best; for beside being quite as compact, the thrust is taken up over so large a bearing area, that a lighter shaft may be used. In this connection, also, the idea has occurred to me, since the impulse (and, therefore, the thrust) usually begins at the forward end of the crank-shaft and ends at the after end (in the usual order in which the cycles are arranged in a multiple-cylindered motor), and this action is continuous, that the strains may possibly be cumulative to the after end. If so, would it not be well to increase the shaft diameter gradually towards that end? The result may have arisen from other causes, but I have certainly noticed in several cases that the after-end bearings were much more worn than those in front. Lastly, in bicycle motors and those of the De Dion type, the shafting is composite, the crank-arms consisting of flywheels with removable crank-pins between. This construction is certainly compact, but entails more or less dismantling to get at the connecting-rod brasses. Quite as good balance in any motor above bicycle size, and certainly greater accessibility, may be obtained, in my opinion, by simply balancing the crank-arms.

The rough forging is machined on a lathe and the blocks cut out to form cranks; and a considerable degree of skill and experience is needed in the process to get the journals absolutely in line, the centres of the crank-pins in the correct angle with each other from the shaft centres, and at the same distance from them; as well as to get the crank-arms in correct angle and balance, without increasing or decreasing the predetermined measurements or total weight. The crank-arms form shoulders against the ends of the bearings practically invariably. After the shaft has been thus machined, the keyways are cut for the half-time gear and the fly-wheel. If lubrication is to be effected through oil-leads, these are next bored out, an operation in which a slight error is sufficient to interrupt the centrifugal flow of the oil. These leads are drilled to meet each other from the ends of all parts of the crank-shaft; the entrances thus made being afterwards plugged. The connecting-rods, which are generally steel drop-forgings, *i.e.* stampings, though castings are employed in some examples, are machined in a lathe; that is, they have their ends—usually stamped open in the middle—bored true to take the bearings for the gudgeon-pin at one end and the crank-pin at the other. The sides of the "big-end" are then drilled, lengthwise with the rod, to take the U-shaped strap (or the cotter pins), which unite the upper and lower halves, into which the "big-end" is then divided, transversely, so that the "brasses" or

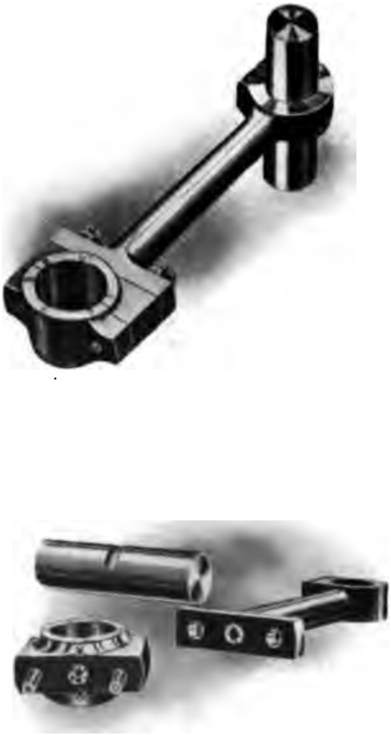

FIG. 19

WOLVERINE CONNECTING-ROD DETAILS

crank-pin bearings may be put in, and, obviously, so that the crank-pin may enter the big-end.

If centrifugal lubrication be intended, the rod is then drilled lengthwise from end to end in a fairly wide oil-lead, and the gudgeon-pin, which has been machined in the lathe to fit, is also widely bored, both lengthwise and centrally, to meet the lead from the rod and convey the oil ultimately to the cylinder walls. Here we shall note that the "Wolverine" method of pinning it appears better than Hautier's, because the latter allows the pin to rotate, which, of course, would render centrifugal lubrication out of the question. Of the two methods above mentioned of uniting the shoe—or lower half—of the big-end to the upper one, the strap, in my opinion, is the better; for if the nut should by any chance work loose off one of its ends, it does not slacken, being held by the other nut, even if the first should actually drop off. Now a single cotter-pin would slacken the brasses at once if it loosened, and if it dropped out would be certain to be caught by the throw (which would probably miss a nut), and do all sorts of damage. In one example the shoe is formed into a head and neck on one side, which fits into a corresponding depression—also necked—on the upper half. But apart from the fact that the shoe is thus fulcrummed on one end, and so pinches the brasses rather than holds them, together, suppose the cotter-pin nut loosens or drops off, what then? Not only dropped brasses, but a dropped shoe, picked up by the throw the next instant and smashed through the crank-case! And suppose the necks break, an entire new rod is required. Perhaps the best practice is to be found in the connecting-rods of that beautifully designed motor the Weller; which, as regards construction, is one of the most original in existence. In this design the big-end of the rod is not halved at all, but formed open at one side into a transverse U shape, one side of which forms the upper, and the other the lower, parts of the big-end, while its ends are bored to take a cotter-pin with a wedging head. Thus the brasses and the crank-pin are slid in at the open side, and the former wedged *evenly* together by the cotter-pin as it is tightened by its nut. It will be noted that all these details emphasise the necessity of an accessible freely opened crank-case.

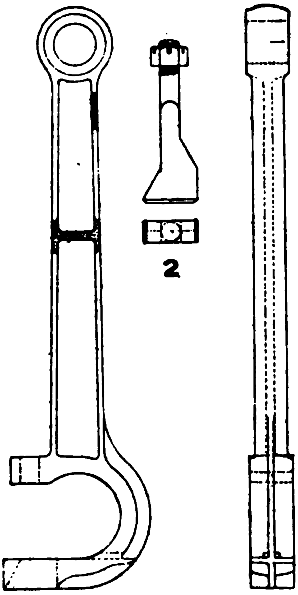

FIG. 20
CONNECTING-ROD AND DETAILS

The cam-shafts are usually lengths of light steel shafting, and have their forward ends squared or keyed to take the half-time gears. The cams, which are machined to shape in a lathe, are then put on and firmly secured in position. In most cases cam-shaft and cams are formed in one forging or casting and machined to diameter and shape respectively. In motors with two cam-shafts the one on the inlet side usually carries the governor mounted in the half-time gear on its forward end. The other end of one of the cam-shafts frequently carries the gearing for the water-circulation pump, the position of which varies in different examples. For instance, its gear is often mounted on a small lay-shaft and driven off the half-time gear, a gear on the other side behind the half-time gear gearing with the magneto. Gears are usually phosphor-bronze castings, and have their teeth cut in a special gear-cutting machine. In some recent examples they are formed of alternate layers of metal and vulcanite or hardened greenhide. A great deal depends on the shape of the teeth as to whether the gears absorb too much power or not. If epicycloidal, that is to say, with the sides of the teeth cut flat and making more or less of an angle with their faces, these faces will *grind* over the sides of the teeth of the other gear, and set up not friction, but "sticktion," and so waste power. If, on the contrary, the teeth are cut involute—that is, with the sides forming a double curve from the bottom of the grooves to the crown of faces—they will *roll* over the teeth of the other gear, which, of course, are similarly cut, in an easy motion without slipping or setting up vibration. Involute gears thus run less risk of being torn out under a sudden increase of load. Bevel gears should always be cut involute, also the change-speed spur gears, the teeth of which are also cut in the same way at their ends to facilitate engagement during rotation.

Here I may state my belief that the chainless bicycle failed to "take" in this country, chiefly because the bevels, instead of involute, had epicycloidal teeth, which set up vibration.

The valve-lifting spindles have practically been described in a former chapter. Sometimes, however, they are halved, and united in a setting-sleeve tapped with a coarse quick-feed thread, so as to vary their lift.* In the Tony Huber engine the inlet-valve lifting spindles have disc cams at one end, which vary the lift of the valves when rotated. Decauville also varies the lift by raising or lowering the cam-shaft. In many of the most recent examples, the guides of these spindles, as well as the cam-shaft bearings, are not screwed on to or cast uniform with the crank-case, but held in a separate casing bolted to the latter outside. This construction has the advantage that the whole mechanism can be more easily removed or examined for repair. Valve-springs vary greatly, both in type and tension. Hitherto only round-sectioned springs have been used; but during the past few months spirals of flat steel — similar to a clock-spring, but spiral—have been fitted. In my opinion, these would not only keep their tension longer than the others for mechanical reasons, but having a greater radiating surface, would resist the temper-destroying heat longer. Springs for a.o. inlet valves are supposed to resist a pressure of two to eight ounces; m.o. springs, especially for exhaust valves, are usually about six times as strong; while lifting-rod springs usually are calculated to resist a pressure varying, according to the example, from 10 to 20 lbs.

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* Cottereau forms a pinion on the upper half, moved by a rack on a cross-shaft in the guides.

Referring now to the connections, we note that the induction pipe consists of an equally branched casting of copper or white metal—which must have easy bends that will not wire-draw the cylinders by any baffling of the mixture — connecting with the carburettor in a single trunk pipe. One or two makers, such as Mors, fit a separate pipe between each cylinder and the carburettor. These castings, after being cleaned and having their joint-faces milled or hand-filed to a true surface, are ready to be bolted to the cylinders with a packing at each joint. The exhaust pipes, usually formed likewise in one casting, are of iron; and after being wound or packed with asbestos cord, are bolted to their cylinder-openings in the same way. The water-circulation pipes—the diameter of which should be fully large, almost equal to that of the induction pipes if the bulk be not inconvenient—are of brass or copper usually brazed into a trunk and branches, and flanged or threaded for unions at their ends for connection to the water-jacket openings. Spray carburettors, as will be gathered from previous chapters, are simple brass or bronze castings, in which all ducts and passages are bored from the solid, and fitted with threaded plugs for easy cleansing. After being lathed smooth, threads are cut or tapped in all parts where a joint is to be made, the ends of the solid projections being threaded to unite the chambers. The various parts are then assembled, the air-valve, if one be used, being ground to its already machine seating. Lugs are also cast, uniform with some portion of the carburettor for attachment to the motor frame; and, in some cases, this attachment is made at the opening from the mixing chamber, which is accordingly flanged to make joint with the inlet passage of the motor. The construction of pumps is, of course, much on the same lines; while that of coils, batteries, spark-plugs, and other accessories has already been generally detailed in previous chapters. Suffice it therefore to say that coils are wound on their cores in a small spinning-lathe, each layer being heavily coated with paraffin or some of the heavier resinous gums, the ends of the windings being attached to brass terminals set in vulcanite plates.

All parts are now ready to be assembled into a motor.

in the erecting-shop, after which the motor is bolted to the testing block and run for short periods—varying from a few minutes to an hour or so at a time—for a day or two to free the working parts from any stiffness. When everything works freely, it is finally tested for its horse-power. If it fail to give the designed power against the brake—a simple band or belt-brake device connected to a spring balance—it is returned to the fitting-shop to have its defects remedied, and then retested until all is as it should be; compression tests with a special indicator being also made. It is then painted with black or aluminium paint of a rust-proof character, these colours being chosen because of their heat-radiating quality. The flywheel calls for but little description, further than to say that its weight depends upon the designed shaft-speed and power of the motor, and is determined according to certain fairly constant formulæ. All the weight, however, should be in the rim, which is an iron or steel casting, either cast uniform with the web and hub, or attached to the hub—which is carefully bored to an exact fit to bring the flywheel directly vertical to the shaft—by steel arms. Sometimes the flywheel carries the governor; and in most cases it is coned on the other side to form the female member of the clutch.

So far as constructional details are concerned, the manufacture of steam motors differs but little from that described in the foregoing pages. The cylinders are castings machined much in the same way, and on the same machine tools. Crank-cases also differ merely in pattern; and, as has already been said, in many instances the only difference in appearance is that there are no water-jackets, their place being taken by packing spaces

which are jacketed with sheet-steel or hardwood. In the lighter engines—and, for that matter, on the heavier commercial vehicles in many examples—the cylinders are bolted to an open frame, holding the reciprocating parts and all shaft bearings, etc. Crank-case construction is, however, the more general; for, including as it does not only the crank-shaft, but all the reciprocating parts below the crosshead or the cylinders, it forms an oil-bath for these as well as a dust-proof casing. Steel or aluminium is the usual metal for the crank-case castings, iron for the cylinders; and horns or attachment arms are cast uniform with the former, the situation and position of which—horizontal or vertical—being purely a matter of the design of the vehicle.

We may, therefore, pass on to the construction of the transmission and change-speed gear mechanism of cars with internal-combustion motors. These are essentially reducing gears, and are either mounted on shafts contained in a gear-box, or, as in the case of the Barber and other variable-feed speed-change gears, so constructed as to vary the rate at which the driving-shaft rotates the driven one, it may be said, by the relation in which both are coupled to one another. Of course, the transmission is effected, and the mechanism extends, from the motor to the road-wheels, but in the former case its first stage lies between the motor and the change-speed gear-box; the latter being the speed-reducing link between the motor and the transmission- or driving-shaft. Now several things must be premised. First, that the shaft of even a low-speed internal-combustion motor—say, running at 800 r.p.m. or so—runs nearly four times faster than it would be safe to allow the wheels of its car to run, even with direct drive to the rear axle, which represents top speed. Secondly, if the motor-speed were reduced, so would its horse-power be, in direct ratio. Hence we note that a certain motor gives, let us say, 20 brake h.p. at 800 shaft r.p.m.; whereas below that rate—though this is reduced by throttling and otherwise as a more convenient method than reducing the car-speed by shifting the gears—*it is no longer a* 20 *h.p. motor for the time being.* With steam, on the contrary, we have our 20 h.p. available at the slowest speed, and no more at the highest. We thus need no speed-reducing gear, as we change speed or reverse by valve-action alone. Nor should we need it with an electric motor, were it not that the torque which gives us our power runs at the slowest twice as fast as we desire to go.

But as we cannot, for obvious reasons, use our top speed only, we must have three or four further mechanical reductions. Thirdly, we must start our motor at something very near its normal r.p.m., before we can begin our speed-reduction either by throttling or any other way. Again, we cannot start it at all if it be coupled to its load, as we cannot then turn the crankshaft. Even if we could do so, it would probably refuse to take that load, not being an industrial gas-engine with a flywheel weighing half a ton or more. And even supposing this were not so, even with the lowest gear, the first speed, in mesh, it would be highly inconvenient to take a flying leap at the car to board it at all. Thus we are bound, for all these reasons, to have a clutch between motor and reducing-gear, unless we have a variable-speed gear, giving zero, *i.e.* transmitting no motion. We also need the latter, not only to reduce speed on the level, but in order that, in hill climbing,

the load on the motor may practically be reduced to a third or a fourth, *i.e.* its driving effect on the road-wheels, while maintaining its normal torque. Again, we must disengage the motor running downhill, so that it may cease to drive: otherwise it would probably drag the car to destruction; and the weight of the car, acting as a driving force on the road-wheels, would cause them to strain the motor in the attempt to overrun it. And it would also be inconvenient to stop the motor at every momentary halt. Fourthly, we cannot, as yet, reverse an internal-combustion motor, albeit some two-stroke marine motors, when pushed above a certain speed, will reverse, to our annoyance, automatically; therefore our gear-box must include reversing mechanism. In point of fact, the law of the land prescribes this for all cars over 550 lbs. weight, and no harm would be done, I think, if the maximum were half that amount.

Clutches all consist of a driving and a driven member, called male and female when the one is contained in the other, the latter usually being the driving member. We need not discuss the different makes or types of these: suffice it to say that they are all either friction clutches—by far the greater majority; jaw clutches; a few magnetic, such as the Jenatzy-Martini; and I believe one or two are hydraulic. Never having seen one of the last variety, I may be excused from attempting to describe it from mere hearsay. The first-named variety, friction clutches, are either coned clutches—the female on its inner and the male on its outer surface, which is either metallic or covered with some non-slipping material, such as leather or fibre—or expanding clutches, the male member expanding within the periphery of the other. Coned clutches vary greatly in construction in different examples: sometimes the flywheel, as previously stated, is coned as the hollow or female member; and, again, either member may be bolted to the flywheel, the other, as may be expected, being the movable one, which is usually mounted on a sliding sleeve secured on the clutch-shaft, so that it rotates with it and normally held in engagement with the other by a powerful spring mounted on the sleeve. In the Panhard clutch, however, it is the male member which is the movable one, and is secured to the flywheel, its sleeve being free to rotate on the clutch-shaft; while the female member is solid with the clutch-shaft, and situated between the flywheel and its male cone.

In expanding clutches, as indicated by the name, the clutch-shaft member consists principally of a halved ring, which, on being expanded by the interior mechanism—generally a system of levers on a sleeve keyed on the clutch-shaft—with which it is connected, grips the inner surface of the motor-shaft member, its expansion being thus effected by the sliding of the sleeve on the clutch-shaft. Jaw clutches are formed either as discs or sleeves oppositely mounted on the shaft ends, that on the motor-shaft being fixed, while the clutch-shaft member is free to slide longitudinally. Both have projections and recesses on their engaging faces, the one thus fitting into the other. But unless the recesses are fitted with buffers in some form or other, the shock of engagement strains the car and motor. Consequently, they are rarely used except for marine motors. As has been said, there are few magnetic clutches in existence; in the Jenatzy-Martini, however, the motor flywheel is made with a recess in the rim, in which is fitted a low-tension field winding. This is earthed to the wheel at one end, secured at the other to a contact ring mounted on the other side of the wheel, and energised through brushes on the contact ring by a dynamo run from the motor. On the other side this coil is covered by a slotted ring—the pole-piece—and magnetises the disc-like clutch-shaft member and a freely rotating ring, which constitutes the armature of the magnetic device thus made. This armature is outside the disc, and as the magnetic lines of force which reach it are so numerous, on account of the diameter of the coil and magnet, despite the small ampèrage of the current, the disc is held in an extremely powerful magnetic grip, the force of which can be readily graduated as the disc and armature are moved to or from the flywheel by the sliding of the sleeve on which both are mounted. No shock is thus experienced in engaging the clutch.

CHAPTER XI

DESIGN AND CONSTRUCTION OF GEARS, CAR FRAMES, AND STEERING DEVICES

AS to the contents of the change-speed gear-box, we already know, from the description of the half-time gearing, that when two gears on different shafts are in mesh with one another the gear with the most teeth, if the driven gear, will rotate the slower (as also of course its shaft), or as the driving gear, cause the other—the smaller one—to rotate the faster with its shaft again. And also, from the direction in which we saw the pump-gear revolve, that if two gears are meshed with one between them, both will rotate in the same direction. These facts govern the working of all change-speed and reversing devices operated with spur-gears. We therefore note that the gear-box—which is constructed, crank-case fashion, in halves, lengthwise, or in three castings, the top one forming the cover, all made and machined in the same way, with lugs or arms outside for frame attachment—carries bearings between these parts for three shafts, in most examples, as well as a bearing at the side through which the shaft of the actuating mechanism enters. These three shafts are (1) the first-motion or *driving shaft*, which is connected to the clutch-shaft, and for a direct through drive, (*a*) through outside bevels to the *counter-shaft*, which carries brake-drums and chain sprockets, or (*b*) by a jaw clutch to the universal-jointed tail-shaft driving bevels on the rear live axle. The jaw clutch is used for gear-box connections because it cannot slip, its typical engagement shock being slighter on account of its smaller size. (2) The second-motion or ***driven shaft.*** This may be either (*a*) a direct-transmission shaft, driving in turn the counter-shaft through bevels outside the gear-box, either on the top or the second and lower speeds (Panhard, Mors, Turcat-Mery, C.G.V., Ader, and others), or (*b*) an alternating shaft, transmitting the drive from and to independent gears on the first-motion shaft (Rochet, Renault, De Dion, Montauban-Marchandier, and still others). In the latter capacity, at certain speeds, usually the top one, it frequently rotates idly—*i.e.* without transmitting the drive—or not at all. (3) The lay shaft, which carries a gear or gears interposed at will between the two gears on the other shafts which give the lowest speed, or engaging through the second speed so as to drive the latter, in order to reverse the drive to the counter-shaft or tail-shaft.

Now the gears mounted on these two first-named shafts are opposed in pairs to each other in various sizes, each pair representing a different speed. These sizes are regulated, so to speak, from the main or driving shaft, smaller to larger respectively, up to the middle speed, as we may understand from the description of the half-time gearing, so as to rotate the driven second-motion shaft at a lower speed. From that point—or rather on either side of it, with four speeds—where their relative speed ratios are about equal, the sizes run larger to smaller respectively to the top speed, where the largest first-motion-shaft gear drives the smallest second-motion-shaft one at the highest speed. Thus, if X and Y are the two shafts, with gears A, B, C, D, corresponding to E, F, G, H, in pairs, A to E, B to F, and so on, for the different speeds the line of increase and decrease occurs, *theoretically*, as shown at MN. But in practice, as will be readily understood, if this relative order of the pairings were maintained, no change in speed would be effected, unless each pair were slid into mesh separately, or rotated freely on their shaft until held rigidly to it by an internal expanding clutch inside each. In the former case, which includes all speed-change gear devices of the Panhard type, we should require an impossibly lengthy gear-box, failing which, as will be seen, we could not get gear C past gear F, or D past G, in dropping from the third to the first speed, or from the top to the third. Still less could we drop from the top to the lowest speed. But this is exactly what the conditions of road-work demand. Consequently, the order of these pairings is arranged on the shafts AE, CG, BF, for a three-speed device, for instance, or AE, BF, DH, CG for four-speeds. However, when the drive is alternate, as from C to G, and thence from H to D, the latter being independent of C, the "theoretical" order can be maintained in a three-speed gear. The above, however, which describes the order in the Panhard and Mercedes

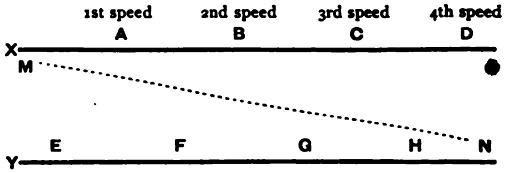

FIG. 21

systems, applies to the majority of others designed on Panhard lines.

The chief characteristic of all such, nevertheless, is that the gears on one or other of the shafts are slid into engagement to give the various speeds. Sometimes the gears are movable on both shafts, and where direct through-drive with an independently mounted top-speed is obtained, the first-motion-shaft gears are practically invariably slid, whether those on the other shaft are or not. Either the shafts themselves are slid lengthwise, or are squared, slotted, or milled with solid keys, so that sleeves on which the gears are rigidly mounted may be slid by the forks of the actuating mechanism lengthwise along them. Now when the teeth of each pair of gears are normally fixed in line, this is where breakages occur in making the changes, which should be done, at whatever speed, with an even motion—"without brutality," as the official translator of a French firm recently put it—which is much easier to describe than accomplish. There must be no slamming or halting from one gear to another. This constitutes the objection to the Panhard type. However, in the Renault system the gears on the second-motion shaft are so mounted on their sleeve that when a change is made, they are automatically lifted out of mesh before being slid along, and then dropped into engagement. In the De Dion system all the gears are in perpetual mesh, with the exception of one in the middle of the first-motion set, which effects all the changes as it is moved by its sleeve, which moves rigid with the shaft. All rotate freely on their bearings except this gear and the second-speed gear on one side of it, the gears on the second-motion shaft being mounted as toothed rings of different sizes on a central common clutch-box, with expanding clutches beneath each; the expansion of one, which is effected by a second lever in the actuating mechanism, contracting the other.

Practically the same result is achieved by the Iden gear on the M.M.C. cars. In this design the first-motion gears are rigid with their shaft, and are in perpetual mesh with the second-motion set, which rotate freely on theirs. This latter, beyond the gears, carries a slotted sleeve, on which the driving-bevel of the counter-shaft is keyed. The second-motion shaft has also two sets of ridges formed upon it, one to engage the sleeve-slots just mentioned, and the other to engage keyways in the hubs of its respective gears. Therefore, as the shaft of this compact and simple gear is moved lengthwise backwards or forwards, it engages the different gears rotating around it for the various speeds. Now the first-speed driving-gear on the first-motion shaft is considerably longer than the others, and always meshes with an additional gear on a lay shaft at its further end, which in turn meshes with the end free gear on the second-motion shaft. Consequently the last-mentioned gear gives the reverse when the shaft projections engage with its hub. Another good perpetual mesh system is the Montauban-Marchandier, which is typical of several others. In this, as before, all the second-motion-shaft gears rotate freely, but between each two gears of this set are jaw-clutch sleeves, sliding on but rigid with the shaft, which, moved by forks actuated by a slot-cam outside, engage with corresponding clutch-members on the rotating free gears. One of these at the end always meshes with an intermediate gear on a lay shaft—as in the Iden system—which again meshes with a small gear on the first-motion shaft. Thus when the first named is put in clutch the reverse is obtained. In a variation of this system, in which the first-motion shaft is bevel driven from the clutch-shaft, the former has two bevels, both free to rotate, which are jaw-clutched either way for ahead motion or reverse.

For light cars various adaptations of the well-known epicyclic-train system are used. In one of these—the system is more or less the same for all in fundamental principle—the internally toothed ring of the epicyclic train is held in a band-brake clutch, thus causing the inter-gearing planets to drive the opposite shaft at a low speed—that of its "sun"—while for the higher speed the whole mechanism is rotated as one by a common clutch to both sides of the device. For the reverse a similar band-brake clutch holds the opposite side, and the driven shaft is thus rotated the other way. The Hautier change-speed gear is said to be a variation of the sun-and-planet system, in which the casing is held in a cone clutch, giving a variable degree of slip.

Turning now to the variable-feed speed-gears, and to the fuller description of the Barber device, which was briefly mentioned with an outline of its working in a previous chapter. Referring back, then, the reader will recollect that the strap of the eccentric had pairs of link-arms, each pair uniting in a clutch-shoe which engaged with the inner face of either of the two hollow clutch discs. Now, as the eccentric rotates, and lifts its strap up and down—gyrating it, that is—the link-arms keep causing the shoe to move backwards, and, as it were, take a fresh foothold and tread the disc forwards. Obviously, the greater the eccentricity of the eccentric, the longer will be the stroke of the link-arms and the "slouching" tread of the shoe, and the faster it will rotate the discs on their axes, supposing for the moment that both are rotatable. The arms, however, are secured to the strap at three equidistant points on either side of the eccentric, and unite each pair with its shoe, to correspond at three points in the disc circumference. But as different pairs of arms are united on either side of the eccentric, it follows that their shoes on one side are not opposite, but intermediate to those on the other. Yet we know the clutch disc on the driving-shaft side of the device does not rotate, but is fixed to the frame, the shaft rotating through its centre. Therefore the backward-moving, forward-treading action of its shoes makes the strap rotate on the eccentric as well as gyrate with it. This effect consequently doubles the stroke of the arms and shoes in the driven disc on the other side.

How then, it will be asked, does the latter disc drive the second, or driven shaft, since it is not keyed to it, but is free to rotate on it at times? The securing medium, then, is a very broad split-ring secured in its hub, and around the shaft, which grips the latter or not, according to whether it is opened or closed. Now this ring has a lug at each end where it is split, and into these lugs a small spindle is screwed with a right- and left-hand thread. Its rotation, therefore, opens or closes the ring to engage the disc with the shaft, or to free it. So much, then, for the driving ahead. Now the little spindle carries a small spur-gear, or pinion, which meshes with a rack on a sleeve on the driven shaft, keyed upon it in the same way as that on the other shaft, and therefore movable lengthwise as the pinion rotates on its spindle. This sleeve, however, carries a larger spur-gear, which, when moved towards the disc by the sleeve, meshes with a smaller gear held down from the frame. And this smaller gear is constantly in mesh with an internally toothed ring formed on the back of the disc. Now when the little split-ring spindle is rotated by the minor lever which controls it *towards* the disc, it does two things at once, namely, opens the ring and frees the disc from the shaft, and rotates its little pinion, which slides the sleeve and its gear into engagement with the stationary pinion supported on the frame. Thus the free disc, still rotating as hard as ever, and also rotating this pinion—with which its toothed ring is perpetually meshed, as we have just seen—drives the driven shaft (through the spur-gear and sleeve) in the reverse way. Reversing the rotation of the little ring-spindle again of course reverses the whole process, slides the gear out of engagement, locks the disc to the driven shaft by closing the ring, and re-obtains the forward drive. But it will be seen, mechanically beautiful though the design is, that everything depends on the strength of the split-ring and the threads of its lugs and spindle, not so much during the reversing process—when, of course, the eccentric is lowered until it ceases to transmit motion—but during the *drive*.

The design of the Ricci variable-feed speed-gear—which also gives zero to maximum—is entirely different, not only because all parts, which are simple in their construction, have much the same relative strength, but because it belongs to the comparatively small class of devices which convert reciprocating into rotary motion. Its gear-box—triangular in elevation—therefore contains four shafts: one at each angle and one in the middle between and below the two at the lower angles. These are the driving-shaft A, on which four cranks or eccentrics are mounted, each at 90° from the next; and the driven shaft B, which carries a long gear with large ratchet teeth engaging the pawls or toggles of four clutches, each of which has a connecting lug on the top. The middle or receiving shaft C acts as a pivot for four links—somewhat of the Stephenson shape—which are mounted with their convex sides facing the driving-shaft A. On this side each link has a lug near the bottom, pivoting it on its shaft C, and another near the top, for the connecting-rod to its crank on the driving-shaft. Each carries a gunmetal slide block in its slot, which is connected by another rod to one of the clutch lugs on the driven shaft, and by a vertical rod to an arm on the upper or rocking-shaft D. Outside a toothed quadrant is mounted on D, engaging with a worm-gear on the controlling-rod. Consequently the links are connected on either side to A and B, and free to swing by their blocks to the arms on the rocking-shaft as they reciprocate.

But as they are pivoted on the lower-seated C, so that the motion of their connecting-rods is directly in line when their blocks are at the top of their slots, it follows that, when the blocks are in that position, the maximum drive is being transmitted between A and B, which therefore rotate at the same rate. On the other hand, when the quadrant rocks the shaft D so as to lower its arms, and consequently lower the blocks, nearly to the bottom of the links, the minimum of motion will be transmitted between A and B. When the blocks are quite at the lowest point in the link slots, zero, or no motion is obtained, intermediate positions in these slots, of course, giving intermediate speeds. The German patent has been obtained for this device, which, as will therefore be seen, is entirely novel. There is also a reversing clutch on the driving-shaft, or the reverse can be obtained in the well-known manner with a rear bevel on the live-axle drive. The nature of the clutch also leaves the rear wheels free to coast downhill, so there is never any risk of overrunning the motor. The Ricci two-speed gear for light cars—also patented in Germany—is a novel modification of the sun-and-planet system. In this the driving-shaft carries both the "suns" or central spur-gears, which are of different size, each meshing accordingly with different-sized "planets," or outer spur-gears. Each pair of planets is mounted on spindles in an internally toothed disc. The larger disc—which contains the larger planets and the smaller sun—is free to rotate on the driving-shaft; but the smaller one opposite is secured to the driven shaft. To give the two speeds one or other disc is gradually jammed against the casing by a ring surrounding the smaller disc. This ring is threaded externally into the casing, and has teeth cut across its lower circumference, engaging with a worm-gear, which thus rotates the ring in or out in its threading against one or other of the discs.

Before closing this chapter with a brief description of the nature and construction of the chassis or frame of the car, its brakes, its steering, and tyres, the principle of the differential gear may be explained. Now, when two wheels are set on the same axle, when a turning is made, unless they are pivoted on the axle—obviously out of the question with driving-wheels, although there are two designs in existence in which all four are driving-wheels—the inner wheel stops, and runs backward *if it can* as fast as the outer one runs forward. This it can always do on the axles of an ordinary carriage, because it is merely a roller. In an automobile, in which it converts, as a driving-wheel, the rotary counter-shaft motion into forward motion by its "sticktion" on the road surface, it ceases to run forward, but could *not* obviously run backwards in time with the outer wheel—as it is held by the driving-chain on its sprocket and that of the counter-shaft—*unless* the latter were so formed as to allow it to do so. Therefore it pivots, and skids sideways towards the plane of the outer wheel because of the centrifugal force thus called into play through the weight of the car. This special counter-shaft formation which prevents this pivoting and skidding is the differential.

Now if a shaft be halved, and bevel-gears mounted on its contiguous ends, with other bevels mounted in spindles, interposed between the first pair and meshing with both, it follows that rotary motion will be transmitted round all four, either way, according (*a*) to the shaft which is being caused to rotate as the driving-shaft, and (*b*) the direction of its rotation; and all four bevels will rotate, and the other shaft be driven round in the *opposite* direction. Therefore, whichever shaft has the stronger rotating force exercised upon it will become the driving-shaft, and the rotary speed of the other will be just as fast in the opposite direction, thus compensating that of the first. This is the *differential* or *compensating* action which enables—as will shortly be seen—the inner driving-wheel to run backwards in making a turning. But if the spindles of the intermediate gears be caused to *revolve*—*i.e.* turn endwise over each other—instead of rotating axially or allowing their gears to rotate, it follows that none of the latter would rotate on each other, but that the whole four would rotate as one body, although leaving either shaft free to rotate, and taking up their previous motion, if any force be exercised on either shaft, as in the first instance. This, then, is the driving action, these spindles being mounted in a central casing halved as the ends of a halved sleeve round both shafts.

These sleeves, then, being united in the differential casing, drive the shafting inside them as one, the driving bevel-gear from either the first- or second-motion shaft being mounted upon it as one sleeve, on either side of the differential casing accordingly. With direct drive, two such bevels are mounted on either side of the latter, facing each other (Mors), or the single bevel-wheel has two bevel faces (Ader), the casing also acting as a dust-proof oil-bath for the differential, and the sleeves being mounted in bearings. Similarly, the same result is achieved by mounting a spur-gear on one shaft as the sun, meshing with planets mounted in one half of the casing, these again meshing with an internally toothed disc mounted on the other shaft by its sleeve, into which the end of the first shaft is projected. Over this disc the other half of the casing is united to the first half, on which is a bevel or sprocket.

The ends of the shafts (*a*) have sprockets mounted on their ends, and are held in bearings on the frame, these sprockets carrying driving-chains to the road-wheels; or (*b*) are mounted in the road-wheels direct, in which case a tail-shaft, held in bearings in a casing and sleeve round the differential casing and its sleeve, carries a bevel meshing with the driving-bevel on the differential. This is the *live-axle* system, in which the axles are halved, counter-shaft fashion, the outer sleeve, of course, forming a dust-proof casing rigidly secured to the rear springs from the frame.

This system, as will be noted, is now being used for all but the heaviest cars, because (*a*) the drive is more direct and freer from excess slacking or back-lash, and (*b*) because the thrust or drive being *between* end-bearings, and more or less central—like that of a first- or second-motion shaft—less power is lost than in the case of the end-thrust of the sprockets *outside* the end-bearings. Sprockets or spur-gears, however, mounted between these bearings, lose less power than bevels; consequently one or two such sprockets are sometimes mounted on the differential sleeve of the live axle—the outer sleeve forming a casing round them—in chain connection with sprockets on the second-motion shaft, the ends of which may be carried in bearings on the frame, in which case, of course, the gear-box bearings may be lighter. For this reason—to get rid of end-thrusts—many horizontal motors, such as the Duryea, James-and-Browne, and others are placed lengthwise in the frame, so as to bring the motor-shaft parallel to the counter shaft or live axle as well as the first- and second-motion shafts. This is also done in some vertical-cylindered motors, such as the Brooke and Motobloc; but probably at some sacrifice of accessibility. Also, instead of bevels, worm-gearing is used for the live-axle drive on some cars, such as the Lanchester. This gives a remarkably silent drive, but it is considered to waste more power than bevels, although less liable to tooth-breakage under sudden strains. The brake-drums are in all cases mounted on the counter-shaft sleeve, or on the differential sleeve of the live axle at the ends close to the driving-wheel hubs; and in all but the lightest cars on the latter as well, the braking mechanism being interconnected.

We now come to the construction of the chassis, which owes more perhaps than any other part of the car to the lessons derived from road-racing. For it must be understood—since the object of designers is to reduce weight as far as possible, consistent with retaining a large safety margin, that road-racing, ever since its inception, has formed, and always will form, a kind of Admiralty test for the strength of the design. Consequently in ten years the engine power of a car weighing one ton has been enabled to be increased thirty- and forty-fold, with a greater safety margin in the modern example. This chassis consists of a parallelogram frame—sometimes narrower in the front and rear than in the middle third—which is secured rigidly through its springs to both axles, and carries the motor, the transmission and change-speed gear, and the car-body. In many examples, however, the two former are carried in an under-frame, supported by the main frame, and occasionally removable, the car-body being secured flush to the latter, above. Occasionally the body is sprung independently of the frame—Jeantaud introduced this system—as in the Jeantaud, Lepape, Crestmobile, and Lanty-Hommen cars.

Constructionally, frames are made of (*a*) lengths of channel steel, of ⊏ shaped section, united at the angles of their ends and cross-pieces with strong angle-pieces or braces, the side-pieces frequently being slotted to take the ends and cross-pieces as well, the horns or dumb-irons being bolted to the side-pieces. (*b*) As just described, but armoured internally with ash, which greatly increases the strength and elasticity of the construction with very little weight. (*c*) Built of ash, armoured on both sides with steel flitches or fish-plates, with channel steel ends or cross-pieces, this construction enabling the side-pieces to be thickened vertically downwards in the middle, thus greatly increasing the strength; (*d*) made of lengths of tubing, threaded into joints which also make joint with cross-pieces and stays, sometimes—as in the Humber frame—stayed lengthwise and vertically, cantilever fashion, to a tubular under-frame; (*e*) as just described, but filled with ash; and (*f*) with side-pieces of pressed steel formed in dies, of E or even a square C section; deep in the middle with lugs to take the counter-shaft bearings, and tapered to the ends from these, with ends, cross-pieces, and under-frames made in the same way, but forming their own angle-pieces for union with the sides.

These are generally known as Arbel frames, from the name of their inventor, M. Arbel, of Douai. Obviously since dies are used, standardisation to two, or at most three sizes is imperative, on account of the size and cost of the dies. Sometimes the side members are wood-armoured inside, though this is scarcely necessary. The end-pieces are mostly broader and shallower, while the shape and number of the cross-pieces of course varies according to the design. In the Decauville chassis the side-pieces forward are extended downwards in one piece to form a bath-like, dust-proof under-frame for the motor, which greatly increases the strength. Lastly, we have the recently introduced jointless one-piece pressed steel frames, perhaps the strongest and lightest of all, made as indicated, but pressed downwards—"from the flat," so to speak—into an inverted ∩ section: flat on the top, deepened in the middle, and tapering from that point to the ends. In both these types the dumb-irons are formed in one with the side members.

The steering-axles of the front wheels are pivoted to

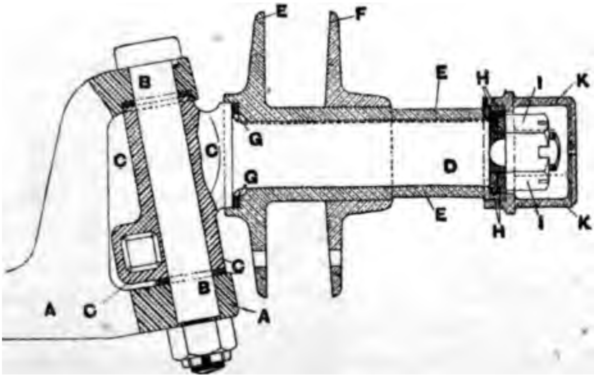

FIG. 22. LONGITUDINAL SECTION OF A STEERING-WHEEL AXLE

A A, front axle; B B, inclined pivoted pin for steering-axle; C C, steering-axle in part section; D, hardened axle; E E E, steel hub; F, removable flange of hub; G G, bearing washer on inner end of the hub; H H, bearing washers on outer end of the hub; I I, Castle nut holding the hub on the axle; K K, cap cover the nut I I.

the fore-body axle, according to the Jeantaud modification of the system invented by Lenkensperger or Ackermann in 1818; but this is done in several ways. Perhaps the strongest construction is that in which the fore-body axle-end forms a D-shaped fork or jaw, the straight part of the D representing the pin of the steering-axle (this [illegible] most general); or else enters the hub of the [illegible] pinned in the [illegible] manner (Hannoyer [illegible] hub [illegible] body of the D. This, because the lateral strain—thrust—is taken centrally *between* the bearing points of the D. With the mere vertical or inverted pins uniting the ends of both axles (Lemoine and some others), let the supports or bearings for the pin in each be never so long, all the lateral thrust is in those bearings, and the breaking-point just between them, the thrust, in my opinion, having a twisting tendency which increases the risk of fracture, more especially when the bell-crank lever forms part of the pin. Axles are soft steel or iron, or nickel-steel forgings.

Much need not be said in regard to the bronze axle-boxes, as their construction is too old and well known. Sometimes roller bearings—in which the axle rotates in a cage-bearing on the faces of rollers which enter between the bars—are used, and unquestionably reduce friction. Yet ball-bearings, in my opinion, are the worst and most dangerous possible for wheel-axles; for although they may reduce friction to a tenth, as is claimed, they only do so because they decrease the bearing surface to about a twentieth or so. The thrust is there just the same, undiminished in weight. Consequently, as the nature of the material of the axle-journal can only be slightly varied, comparatively speaking, by case-hardening, it is rapidly cut into a groove and weakened, as its thrust is taken on one-twentieth or so of the area. Nor can the balls stand the strain, being always liable to break and seize the axle-journal. Ball-bearings—which have been tried on the railways and condemned a generation ago on these accounts—may be all very well for plane surfaces gyrating on one another, but not for rotating cylindrical ones.

The steering mechanism of automobiles consists of (1) short horizontal arms, either rigid with the pins of the steering-axles or with the axles themselves, each forming a kind of bell-crank with its axle of equal angle to the angle thus formed on the other. These arms are always on the same side of the axles, in front or behind, but in all cases are connected in a free joint, by a rod of such a length that (*a*) their axles are rendered parallel or in line with one another at all times, and (*b*) that they shall always be either parallel or converge, so that if extended rearward their converging point would always be on a line parallel to the rear axle of the car. All this, combined with the differential action, *approximately*, makes the four wheels rotate in a common axis in the centre of the rear axle, and gives a turning angle of 30° to about 44°. Sometimes, instead of one distance rod there are two of equal length; indeed, several more pairs exist in some designs. These pairs, of course, are united in a common arm, the other end of which is fixed at a point, or in an equal armed bell-crank, similarly pivoted. These various systems, however, need not be detailed.

Rigid with these axle-arms, either in line or at a convenient angle with one of them, is the second part of the mechanism, (2) an arm forming a bell-crank with the axle-arm, either at the same end or the other end of the coupling-pin, or rigid with the axle-arm on the axle to form a bell-crank. To this is hinged (3) a bell-crank tie-rod, the steering-rod, which is attached at its other end, usually in a ball-joint on one end of (4) the steering-arm. This lever is rigid with a toothed quadrant engaging with a worm on (5) the steering-shaft, which carries the wheel, or as part of any other device, which when actuated by the steering-shaft will cause it to move to and fro, pull or push the steering-rod, and thus move the bell-crank and axle-arm one way or the other. But though this is the typical system, any device which will impart the necessary to or fro movement to the steering-axle is sufficient, so long as it is sufficiently sensitive to movement from the steering-shaft to the steering-axle, but *not* in the reverse way. Nevertheless, while its action must be irreversible so that the driver may for the moment release his grip of the steering-wheel, it must have a certain amount of elasticity lest some obstacle or hole in the road may smash the steering-gear, or axle, or road wheel owing to the deadness of the mechanism. Thus worm-gear and quadrant devices, feed-screws, and so forth, though in place on the steering-shaft, are too irreversible at the other end of the system. Still, if anything, they are not sensitive enough. In one system (Malicet-Blin's) double rollers on the head of the steering-arm engage with a disc cam on the end of the steering-shaft, so that the slightest rotation of the cam by the shaft will move the arm with greater elasticity and yet no back-lash.

A word as to tyres. The reader must not be misled by statistics and percentages, or even experiences quoted in controversial argument in "letters to the editor." It is true that the average of pneumatic tyre failure has been shown on paper to be some 30 %, thus making out the car thus tyred to be like a horse which casts a shoe every other day. But this is because some people's luck is so bad that their failures bring this average percentage up with a rush. Putting the experience of these unfortunates apart, the failure percentage is not, in my experience, greater than 10% or 15% for mere temporary failure, nor for total failure more than perhaps 5%. My friends and I may have been lucky, but I think not. Some tyres, equally good on the same car, have the knack of "finding it," whilst others on the other wheels will happen to run hundreds of miles without even a puncture. There is no such thing as a really "unpuncturable" pneumatic tyre, but I really believe that the next thing to it is a properly shaped leather outer cover, not strapped on, as straps rot, and the holes tear in continuous wet weather, but lapped in under the rim like an ordinary cover. They do not creep, as might be expected, for if the tyre be properly inflated, *i.e.* almost wood-hard, they are held too tight to creep. They resist nails and thorns and small fragments of broken glass—these are practically all the causes of woe in road travel. Failing these, I recommend tyres that when punctured do not collapse, or solids on the rear wheels with a heavy touring car; as the latter, of course, though costly and slowing, wear for a long time and cause no anxiety, while the former certainly enable one to get home, if also somewhat slow. On the other hand, the leather band undoubtedly does reduce the cost of maintenance, so far as there has been time to judge of its merits, to very nearly a halfpenny per mile instead of the quoted average two-pence; though again, with good pneumatics and an ordinarily good make of cover, and average good luck, a penny is nearer the mark. Not all canvas-lined covers are good, but some are excellent, and *almost* non-puncturable. The nearest thing to a puncture-proof tyre I have seen was one in which the wheel-rim completely surrounded the tubular part, leaving only the solid tread exposed. As to pneumatics, my advice is, read the advertisements, cut them out carefully—then roll them up, put them in a hat, and draw the lucky one. They are nearly all good of their kind, and much more reliable than is generally thought. *Nunc est* "*bibendum.*"

INDEX

Accumulators, 134-7
—, elements, 135, 136
— —, the Faure type, 135, 136
— — —, Edison, 137
Armature, the, 129-33
—, construction of an, 131
—, function of an, 132, 133
Avant-train, the, 23
Axles, 207, 213, 214
—, boxes, 214
—, live, the, 209, 210
—, steering, 213, 214

Batteries, 58
— (see also Accumulators), 134-7
Bearings, ball-, 171, 214
—, plain, 171, 173, 174
—, roller-, 214
Beau de Rochas, A., 6, 40
— —, cycle described, 44, 45
— —, essential laws of, 154, 155
— — and short-stroke type, 155
— — — adiabatic ignition, 155
Benz, Carl, 11
— —, first car imported, 20
Blackburn, 8
Boilers, description of typical, 110-23
—, fire-tube, 111
— —, construction of, 112
—, water-tube, 112
— —, construction of various types, 113-15
—, the Sergeant, 114
— — Toledo, 115
— — "flash" type, 115
— — —, working conditions of, 116, 117
Boilers, the "flash" type, methods of control in, 117
— — Gardner-Serpollet, 118
— — Chaboche, 119
— — White generator, 120-22
Bollée, Amédée, 13, 15, 19
—, Leon, 25
Burners, various types of, 123-7
—, pan-, 124
—, Ravel's petroleum, 123
—, single-jet, 124
— —, in multiple, 125
—, steam-inducing, 125
—, the Hydroleum, 126

Cams, 36, 41, 42, 46, 102, 105
—, the Chenard-Walcker, 161
Cam-shaft, 36, 41, 43, 46, 105
—, construction of, 176, 177
Carburettor, the, 36, 39
—, various types, 69-75
—, construction of, 191
—, atomising, 70-4
—, bubbling, surface, and wick, 70
—, Delamare - Deboutteville and Malindin's, 9
—, Huzelstein type, 73
—, James and Lunkenheimer type, 74
—, mechanical distributors, 75
Castings, 163, 164
—, patterns for, 163
—, making, 164, 165
—, "headless" type, 165
— — — with open-panel jackets, 166
— with separate heads, 167, 168
— — jackets, 168, 169

Castings, Napier practice, 170
—, suggested practice, 170
— for the crank-case, 171–4
—, crank-case, open, 173
Catley and Ayres, 8
Chassis, the, 211, 213
— —, effect of road-racing on construction of, 211
— — Arbel, 212
— —, one-piece pressed, 213
Circuit, the electric, 60–2, 67, 129, 132, 133, 136, 138, 139, 142–4
Clerk, Dugald, 9
— —, two-stroke motor, 13
Clutch, the, 194
—, need for the, 194, 195
—, types of, 195–7
Coil, the high-tension, 58
— —, working of, 61
—, the low-tension, 65, 66
—, construction of a, 191
Commutator, the, 41
—, description of the, 131, 132
—, function of the, 132, 133
Compound petrol-electric motor, the, 23
— — —, types of the, 146–51
— — —, weight of the, 151
Condenser (electric), 58
— (steam), 127
Connecting-rod, the, 36, 38
—, construction of, 186, 187
Contact-breaker, the, 60, 61
Controller, the, 141, 142
Counter-electro-motive-force, 142–4
Crank-case, the, 36, 43
—, construction of the, 171–5
Crank-shaft, the, 36–8
—, construction of the, 184–6
Cugnot, Capt. N. J., 2
Cycle, definition of the, 40
—, Beau de Rochas, 44, 45
—, Robson, 84, 85
—, Heasman, 89
Cylinders, the, 36, 38
—, construction of the, 176, 177
—, cooling systems, 49, 50

Daimler, Gottlieb, 9–13
— —, V-shaped motor, 12
Dance, Sir Charles, 4
Day, Joseph, 9
— —, motor, description of, 86
De Dion and Bouton, 12
— — change-speed gear, 199, 201
— — boiler, 113
— — design, 53, 182, 185
Delahaye, 14
Delamere-Deboutteville and Malindin, 9, 11
Design, general tendencies of, 152–9
— of the Standard motor, 156
—, complication in, discussed, 158
—, standardisation of, 159
—, to improve carburation, 159, 161
— — — methods of governing, 161
—: the Chenard-Walcker system, 161
— of change-speed gears, 162
Differential-gear, the Pecqueur, 6
—, theory of the, 208
—, need of a, 208, 209
—, construction of, 209, 210
Durkopp, 14
Dynamos, 147–51

Electrolyte, 136, 137
Electric-ignition, 54, 57–68
— motors, 128–46
Ellis, the Hon. Evelyn, 20
Exhaust connections, 191
— valves, 180, 181
— — springs, 190

Field-magnet, 128, 130, 132, 138–41
Fifth wheel, 4
Financing, French, 19
—, British, 24
First car imported, 20
Flywheel, the, 36, 38, 192

Gas Motoren Fabrik, 10
Gautier, 13
Gears, 41
—, two-to-one, 43
—, construction of, 189

Gears, change-speed, 193–207
— —, theory of, 198–201
— —, need of, 194, 195
— —, types of, 201–7
—, variable-feed, types of, 162, 203–7
Governing, methods of, 78–82
Governor, the, 77
— —, action of, 77
— —, control of, 78
Grenville, R. N., 8
Gudgeon-pin, situation and securing of the, 184
Gurney, Sir Goldsworthy, 4

Hancock, Walter, 4
Henriod's motor, 15
— "Pandora" gear-box, 162
Hewetson, Mr. Henry, 20
Holt, H. P., 8

Ignition plugs, construction of, 181
— systems, 53–9
— —, hot-tube, 54
— —, bougie, 55
— —, hot-chamber, 55
— —, adiabatic, 56
— —, catalytic, 56
— —, electric, described, 54–7
— — — — parts employed, 57–9
— — — — — in high-tension, 58
— — —, working of high-tension, 60–3
— — —, wiring of high-tension, 62
— —, rupture-spark system, 64
— —, parts employed in, 64
— —, working of parts employed in, 65
— —, low-tension system, 66
— —, the "intensifying gap," 67
Indiarubber tyres, 8
— —, remarks on, 216–8
Induction-pipe, the, 69, 76
—, function of the, 76, 77
—, construction of the, 190, 191
Inlet-valves, 36, 40, 42, 48, 178–81

Jeantaud, 14
Journal, Le Petit, 18

Kane, of Chicago, 14
Knight, J. H., 8
Krebs, Commandant, 160

Langen, Geheimrath, 7, 10
Lawson, Mr. H. J., 22
Lefebvre, Leon, 14, 15, 173
Lenoir, 7
Lepape, 14
Levassor, M., 19
Leyland, the, steam waggon, 25
"Lifu" boiler, the, 27
Liverpool trials, the, 26
Locomotive Act, 1836, the, 5
Lubrication, systems of, 51–3
Lubricator, the Dubrulle, 52
— — F.I.A.T., 52
— — Holt, 51

Macadam, 4
Maceroni and Squire, 5
Mackenzie, H. A. O., 8
Magnets, the, 36
— —, Simms-Bosch, 38, 39
— —, high-tension, 63
— —, Houpied and Goodson, 64
Maudslay, 53, 172, 178, 182
Maybach, Carl, 14
Mercedes, 27
Mors, 14, 27, 73, 190, 199, 209
Motor, definition of a, 35
—, the internal-combustion; four-stroke type, 36–82
—, parts of a, 36, 37
—, single-valve, the Selbach and the Bailleul, 46
—, Robson's, Clerk's, and Day's systems, 84–6
—, Smalley, Evans, and others, 86, 88
—, Heasman, 88–90
—, steam, 96–109
— —, differences of, 96–102
— —, working of, 102–9
— —, construction of the Négré, 106–8
—, electric, 128–46
— [illegible] parts of an, 128,
[illegible] 110–7

Motor, electric, series-wound, 138
— —, shunt-wound, 138
— —, compound-wound, 139
— —, multipolar types, 140
— —, voltage in, 143, 144
— —, necessary weight of, 145
— —, efficiency of, 145
—, compound, 147–51
— —, Patton's system, 147
— —, Eppstein's system, 147
— —, Lohner-Porsche system, 148
— —, Germain system, 148, 149
— —, others, 150
— —, weight of, 151
Motor-launches, the earliest, 12
Motors, agricultural, 32
— —, advantages of, 33

Napier cars, 27, 28
— practice, 170

Otto, Dr., 7

Panhard and Levassor, 13
— change-speed gear, 199–201
— clutch, 196
—, a discovery, 67
— practice in construction, 168
Paris Sailing Club, 12
Pecqueur, differential gear, 6
Peugeot Frères, Les Fils de, 14, 19
Piston, the, 36, 38
—, construction of, 182, 183
— -rings, construction of, 183
Pneumogastric nerve, the, 77
— —, comparison of, 77
— —, functions compared with governor, 38, 79, 80
Pretôt, 23
Pumps, 49, 50
—, construction of, 191
"Pygmée" motor, the, 23

Race, the first Paris-Rouen, 18
— — — — -Bordeaux, 19
— — Chicago-Waukegan, 20
— — New York-Pittsburg, 20
— — Paris-Marseilles, 21
— — — -Dieppe, 25
— — — -Amsterdam, 25
Race, the second Paris-Bordeaux, 26
— — third Paris-Bordeaux, 26
— — Paris-Berlin, 27
— — — -Vienna and Gordon-Bennett, 28
— — — -Madrid, 29
— — Circuit du Nord, 30
— — Irish Gordon-Bennett, 31
Racing, the safety of, 31
— — result of, 211
Radiators, 49
Raffard's electric tricycle, 11
Ramsay and Wildgoose, 1
Randolph, C., 8
Ratchet-and-pawl, 2, 3
Ravel, Pierre Joseph, 8
Robson, James, 9
Roger, M., 14

Salomons, Sir David, 21
Sarassin, M., 12
Serpollet, M. Leon, 14
— engine, the, 105, 106
— "flash" boiler, the, 118, 119
Silencers, 91
Silencing, methods of, 91–5
—, the Dunlop device, 94
— — rotary device, 94
— — Scottish boiler device, 95
Simms, Mr. F. R., 20-2
— gear-box, 162
— -Bosch magneto, 38, 39, 64
Steering-axles, 213, 214
— devices, 215, 216
Sturmey, Mr. H., 21

Tenting, 13
Thompson's steam carriage, 8
Todd, L. J., 8
Torque, 133
Trevethick and Vivian, 3
Trials at Versailles, 25
—, A.C.G.B.I. to Glasgow, 27
— — of 1902, 29
— at Cromer, 27
— at Liverpool, 25
—, steam waggon, 32
Tyres, 216–18

Valve-lifting spindles, 36, 41, 42
— — —, construction of, 189, 190
—, m.o., 179, 180
— springs, 190
—, Selbach single-, 46–8
—, tappets or rockers, 42
Valves, the, 36, 40
—, description of, 41, 42
— —, in steam motors, 101
—, construction of, 180
—, boxes, 178
—, chests, 43
—, compound, 48
—, D'Ecquivilly, 48
—, downward opening, central, 180, 181
Valves, gears, 36, 42, 81, 101, 189, 190
— — in steam motors, 102–5
— — — —, Stephenson, 103, 104
— —, variable lift, 81
— exhaust, 180, 181
— inlet, 36, 40, 42, 48, 178-81

"Walking-devices," 4
Water-circulation pipes, 36, 49
— — —, construction of, 191
Weller motor, the, 41, 159, 169
— connecting-rod, the, 188
"Wire-drawing," 70–6, 77, 79

Zborowski, death of Count Elliott, 29

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CONTENTS

PAGE
General Literature, . . . 2-20
Ancient Cities, ... 20
Antiquary's Books, . . 20
Arden Shakespeare, . . 20
Beginner's Books, . . . 21
Business Books, . . . 21
Byzantine Texts, . . . 21
Churchman's Bible, . . 22
Churchman's Library, . . 22
Classical Translations, . 22
Classics of Art, . . . 23
Commercial Series, . . 23
Connoisseur's Library, . 23
Library of Devotion, . . 23
Illustrated Pocket Library of Plain and Coloured Books,
Junior Examination Seri[illegible]
Junior School-Books, .
Leaders of Religion, .
Little Blue Books, .
Little Books on Art, .

PAGE
Little Galleries, . . . 27
Little Guides, ... 27
Little Library, . . . 27
Little Quarto Shakespeare, 29
Miniature Library, . . 29
Oxford Biographies, . . 29
School Examination Series, 29
School Histories, . . . 30
Textbooks of Science, . . 30
Simplified French Texts, . 30
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[illegible] 23-27
[illegible] 27

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